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THE

and

GNEISSES, GABBRO-SCHISTS, AND ASSOCIATED ROCKS

OF

SOUTHWESTERN MINNESOTA

BY

CHRISTOPHER WEBBER HALL

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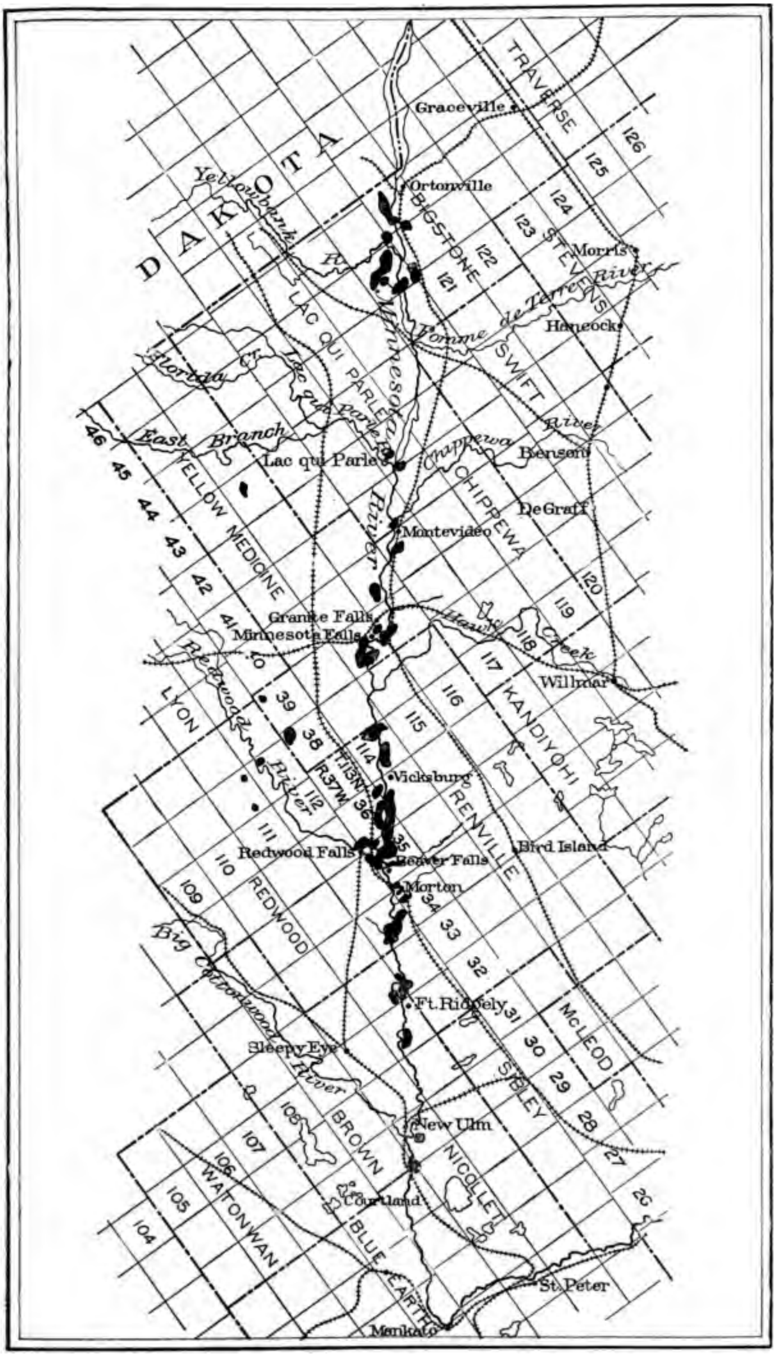
ILLUSTRATIONS.



MAP OF A PORTION OF SOUTHWESTERN MINNESOTA, SHOWING OUTCROPS OF CRYSTALLINE ROCKS.

THE GNEISSES, GABBRO-SCHISTS, AND ASSOCIATED ROCKS OF SOUTHWESTERN MINNESOTA.

By C. W. HALL.

CHAPTER I.

INTRODUCTION.

The territory from which the material for this paper was gathered embraces that part of the Minnesota River Valley lying between Courtland and Ortonville and that portion of the State of Minnesota to the west and south of the river named wherever gneisses are found. (See Pl. I.) The area is about 5,500 square miles in extent.

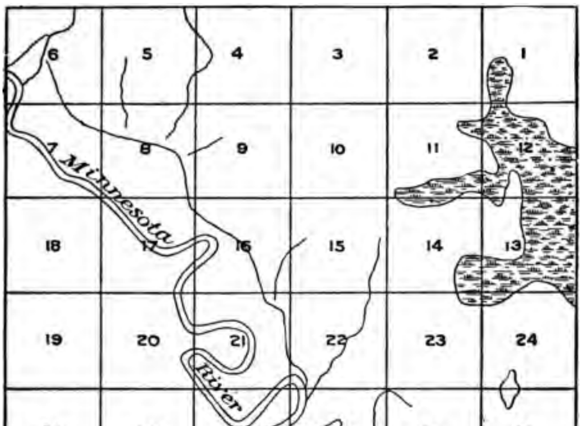


FIG. 1.—A township from the United States Government survey—T. 110 N., R. 30 W., Minnesota.

This entire area has been platted by the land surveyors of the Government, and geologists are thus enabled to locate accurately every sample gathered. Wherever in the following pages a definite location is given, the township and range are named, and the paces, on the basis of 2,000 to the mile, north and west from the southeast corner of

the section are stated. Occasionally, however, it was found that the surveyors' monuments and section posts had disappeared, and then the distances were estimated.

Although the area embraced in this study reaches well up to the headwaters of the Minnesota River, the rock elevations do not attain great heights above the sea. Probably no outcrop occurs at a higher elevation than 1,200 feet. This portion of the State is deeply drift covered, and wherever the rocks appear above the present high-water mark of the Minnesota River they protrude in well-rounded knobs or bosses, sometimes of small size, and never of great extent, either in height or in area. As a consequence of the heavy drift covering, we find few outcrops upon the prairie beyond the morainic bluffs which bound an ancient flood plain of the Minnesota River. These few are

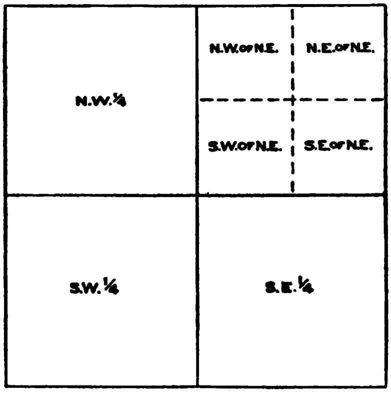


FIG. 2.—A section 1 mile square. One mile=2,000 paces.

the highest masses of an eroded rock surface protruding through the glacial drift.

The flood plain of the Minnesota River is from 1 to 5 miles wide throughout its course from Ortonville to and beyond New Ulm, and was formed while the valley was a channel of outflow from Glacial Lake Agassiz, extending northward through the present Red River Valley. Projecting through this flood plain are many exposures of gneisses, gabbro-schists, diorites, and diabasic effusives. In the 120 miles between Ortonville and New Ulm the rocks named "often fill the entire valley, 1 to 2 miles wide, rising in a profusion of knobs and hills 50 to 100 feet above the river."[1]

Unless there be assumed a considerable elevation of the central portion of the continent, it must be supposed that during Glacial or pre-Glacial time the descent of the River Warren was a gentle one. Such is that of its successor, the Minnesota River, of post-Glacial time. This fact, and the presence, throughout the upper portion of its course,

[1] The Minnesota Valley in the Ice age, by Warren Upham: Proc. Am. Assoc. Adv. Sci., 1883, p. 215.

of crystalline rocks, have determined the slight depth below the Warren flood plain to which the bed of the river has been eroded. Few rapids occur, and these are where the river crosses the strike of the gneisses. The Minnesota River at Courtland stands 807 feet above the Gulf of Mexico, and the elevation of Bigstone Lake, a widening of the river near Ortonville, is 962 feet.

The few exposures occurring outside this ancient river valley lie in the towns of Omro, Posen, Echo, Vesta, Johnsonville, and Vaill, south and west of the Minnesota River. The next exposures in these directions beyond the townships named are the glaciated knobs of red quartzite in Cottonwood and Watonwan counties, and other quartzite exposures among the Coteau des Prairies—called Shining Mountains[1] by the early explorers of the Northwest—in Rock and Pipestone counties, from which, with many a superstitious ceremony, the Indian quarried the soft catlinite for his pipes.

North and east of the Minnesota River the Leaf Hills and the uniformly thick beds of till cut off the Minnesota River Valley series of gneisses and associated rocks from the granites and schists of the Mississippi Valley, whose most southwesterly exposures, so far as known, lie in Stearns County.[2]

In locating the geological boundaries of the Minnesota River formations, as has been done on the accompanying maps, sometimes an approximation only is possible. Wherever the drift covering conceals the underlying rocks the rock boundaries are denoted by dotted lines.

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[1] Travels through the Interior Parts of North America in the Years 1766, 1767, and 1768, by Jonathan Carver, Dublin, 1779, p. 45.

[2] Preliminary report on the geology of central and western Minnesota, by Warren Upham: Eighth Ann. Rept. Geol. Nat. Hist. Survey Minnesota, p. 75; and also The geology of Ottertail County, by Warren Upham: Final Rept. Geol. Nat. Hist. Survey Minnesota, Vol. II, p. 546.

CHAPTER II.

SUMMARY OF EARLIER OBSERVATIONS.

In the mass of material published by the earlier explorers and the later scientific investigators who have given their attention to the northwestern Territories and States, little reference is made to the rocks which form the subject of the present study. For the purpose of historic and scientific reference the following list of titles and abstracts is made. The order is chronological.

SEPARATE PUBLICATIONS.

1. CARVER (Jonathan). Travels through the interior parts of North America in the years 1766, 1767, and 1768. Dublin, 1779.

Carver wrote an exceedingly interesting book, but he said very little on the geology of the Northwest. The St. Peter (Lower Silurian) sandstone is briefly mentioned, not by that name but as a snow-white rock crumbled outwardly by the wind and weather. The crystalline rocks farther up the Minnesota River Valley are not alluded to.

2. KEATING (William H.). Narrative of an expedition to the sources of the St. Peter's River, Lake Winnepeek, Lake of the Woods, etc., performed in the year 1823, * * * under the command of Stephen H. Long, U. S. T. E. London, 1825. 2 vols.

Professor Keating, of the University of Pennsylvania, geologist and historiographer of Major Long's expedition, indulged in many philosophical reflections on the character and constitution of the granitic rocks met with in the explorations of the party with which he was connected (Vol. I, pp. 362–382, and elsewhere). In the primitive rocks above Redwood Falls it seemed to Keating "as if four simple minerals, quartz, feldspar, mica, and amphibole, had united here to produce almost all the varieties of combinations which can arise from the association of two or more of these minerals, and these combinations were in such immediate contact that the same fragment might, as we viewed one or the other end of it, be referred to different rocks; while in some places granite was seen perfectly well characterized; in others a gneiss, mica-slate, greisen (quartz and mica), compact feldspar (Weisstein of Werner), syenite, greenstone, and the syenite with addition of quartz, forming the amphibolic granite of D'Aubuisson, were equally well characterized. The only rock composed of these principles which we did not observe,

but which may perhaps exist there, is the graphic granite (pegmatite, Hauy)." (P. 365.)

Keating also advances the suggestion that the Coteau des Prairies, as the dividing ridge between the waters of the Mississippi and those of the Missouri, "is doubtless the grand dike which has obstructed the latter in its progress eastward and caused it to flow southwardly through a distance of many hundred miles, before it could again resume a direct course to the former." (Vol. II, p. 220.)

3. BELTRAMI (G. C.), esq., formerly judge of a royal court in the ex-kingdom of Italy. A pilgrimage in Europe and America, leading to the discovery of the sources of the Mississippi and Bloody river, with a description of the whole course of the former and of the Ohio. Printed for Hunt and Clark. London, 1828. 2 vols.

Beltrami several times alludes to the rocks of the Minnesota River Valley. Those at the Redwood River he speaks of as granite of a beautiful and varied quality. It is not necessary to make here any quotation from Beltrami's work.

4. FEATHERSTONHAUGH (G. W.), U. S. geologist. Report of a geological reconnoissance made in 1835, from the seat of government, by the way of Green Bay and the Wisconsin Territory to the Coteau de Prairie. Document 333. Printed by order of the Senate. Washington, 1836.

Featherstonhaugh mentions gneiss at the Grand Portage (Granite Falls), east of Lac qui Parle, as dipping southeast, with an almost vertical inclination (introduction). He further says concerning this rock that it has "little or no mica" (p. 28), and that it "resembles granite in every particular except its stratification" (p. 149). Granite, he says, was of frequent occurrence, and was the only rock seen in places beyond the mouth of the Waraju (Cottonwood) River toward the northwest, the last seen described as consisting of "immense masses of granite in place, isolated from each other, and occupying several hundred acres. Some of these masses are 25 feet high; they extend 6 or 8 miles down the valley and give its name of Eatatenka or Great Rocks to the lake [Bigstone Lake]." (P. 157.)

In a later publication[1] the same author mentions many localities between Redstone (Courtland) and Bigstone Lake, where granites occur, and many details concerning them are given.

5. NICOLLET (J. N.). Report intended to illustrate a map of the hydrographical basin of the Upper Mississippi River. Senate Doc. 237, 2d sess., 26th Congress, February 16, 1841.

The valley of the Minnesota River, together with other tributaries of the Mississippi, is mapped. The general trend of the Minnesota River and the situation of its branches are portrayed with remarkable accuracy, considering the fact that there were no primary surveys at that time to give guidance to the work.

[1] See No. 6, following page, Vol. I, Chapters XXVIII to XXXV.

6. FEATHERSTONHAUGH (G. W.). A canoe voyage up the Minnay Sotor. London, 1847. 2 vols.

The geological observations of Featherstonhaugh in this expedition have already been referred to. He saw many bowlders of the primitive rocks, from escarpments of vertical granite and rugged granite hills "resembling parts of Dartmoor." (Vol. I, p. 325.) Elsewhere he saw "immense masses of granite all quasi-stratified, in laminæ about an inch broad." (Ibid., p. 333.)

7. ALLEN (Lieut. J.). Map and journal of, in charge of escort accompanying Schoolcraft's expedition to the sources of the Mississippi. American state papers, documents, legislative and executive, of the Congress of the United States from the first session of the Twenty-fourth Congress inclusive, Vol. V., Military Affairs, pp. 312–344.

Lieutenant Allen, in this rather detailed report, published a map of the region now embraced in southwestern Minnesota, which was compiled with great care from the information then at hand. The chains of hills and mountains as located on the map show the explorers' and author's views of the situation and trend of the geological formations, which have had so marked an effect on the topography of the region.

8. OWEN (David Dale), U. S. geologist. Report of a geological survey of Wisconsin, Iowa, and Minnesota; and incidentally of a portion of Nebraska Territory. Philadelphia, 1852.

With the advent of Owen into the Northwest we enter the time of more active and systematic research. This geologist, with his chief assistant, Dr. Norwood, and such aids as Shumard and Whittlesey, came for the distinct purpose of throwing light on the geological character of the territory comprised within the field of operations, and of presenting such practical results as might be drawn therefrom by Government officers and prospective settlers.

Shumard began an examination of the St. Peter (Minnesota) River, but an attack of pleurisy at the Redwood River put a stop to his further progress. He located the boundary between the quartzite conglomerate and the granitic rocks of the valley nearly opposite New Ulm. "About 1 mile in a straight line above the mouth of the Waraju, and 3 miles by the course of the river, we found some outliers of coarse conglomerate and granite a short distance from the bank of the stream. The conglomerate is composed mainly of quartz pebbles and bowlders, some of the latter 10 inches in diameter; the whole cemented with a siliceous material. . . . The course of the exposure is nearly east and west, with a dip toward the south of 20°. . . . The granite is 100 yards removed from the conglomerate. . . . Flesh-colored feldspar forms nearly two-thirds of the granite." (P. 491.)

9. WHEELOCK (J. A.), commissioner of statistics. Minnesota: its place among the States. First annual report of the commissioner of statistics for the year ending January 1, 1860. Published by authority of law. Hartford, 1860.

Touching southeastern Minnesota, Wheelock says: "From the head of Lake Superior a narrow granitic spur of this primary rock, divested of the volcanic débris in which the mineral wealth of Lake Superior is embedded, stretches southwesterly under the drift, beyond the boundary of the State, revealed only when it crosses the Mississippi at Sauk Rapids, the Minnesota between the Cottonwood and the Redwood, and the Big Sioux at Sioux Falls. This granitic seam intervening in the sandstone has a breadth upon the streams which it crosses of from 40 to 50 miles" (p. 53).

10. ANDERSON (Charles S.) and CLARK (Thomas). Report on geology and plan for a geological survey of the State of Minnesota. Made in accordance with a concurrent resolution passed by the second legislature of Minnesota, March 10, 1860.

This report of Anderson and Clark merely alludes to "an extensive range of the primitive system of rocks" . . . which "appear on the Minnesota River about the mouth of the Redwood River. Although sometimes termed a mountain by geologists, the highest elevation of these ranges does not exceed 2,000 feet above tide water." The breadth of this granitic region is out of proportion to its elevation—considering it a mountain—being about 60 or 70 miles. . . . Here are also found nearly all varieties of the granitic and metamorphic rocks (p. 5 et seq.).

This report is of historic interest in that it marks the beginning of geological surveys by the State of Minnesota.

11. HALL (James). Notes upon the geology of some portions of Minnesota, etc. Transactions of Philosophical Society, Vol. XIII, N. S., Philadelphia, 1869.

Professor Hall, in speaking of an area about Courtland, says: "Then rises to the surface a reddish-brown crystalline rock having a granitoid aspect, but when critically examined is found to consist mainly of quartz and feldspar without the perceptible admixture of other minerals. . . . We have, therefore, an almost continuous exposure of the strata for more than 100 feet in thickness. There is a distinct dip to the northeast." (P. 330.) Further on he adds: "I conceive it to be sufficiently demonstrated that the quartzites at Redstone Ferry [Courtland] on the Minnesota River—those near the sources of the Little Cottonwood, . . . together with those of the escarpments of Pipestone, . . . are of the same age. These quartzites I regard as of the age of the Huronian formation of Canada and the quartzites of Wisconsin." (P. 338.) Turning now to the older rocks, Professor Hall says that around Redwood Falls they are gneissoid, and "in many places these rocks are intercalated by steatitic or glauconitic beds, and the entire mass is in a state of decomposition to the depth of 80 or 100

feet. It would be of much interest," he continues, "to ascertain the relation which the dip and direction of these older gneissoid rocks bear to the succeeding quartzites, which evidently belong to the Huronian system" (p. 335). (See fig. 3.)

12. CHAMBERLIN (T. C.) and assistants. Geology of Wisconsin, survey of 1873–1879. By the commissioners of public printing, Madison. 4 vols. Vol. II, 1877; Vol. III, 1880; Vol. IV, 1882; Vol. I, 1883.

In the discussion of the "quartzites of Barron and Chippewa counties, compiled from the notes of Messrs. Strong, Sweet, Brotherton, and Chamberlin," reference is made to the quartzites near New Ulm, Minnesota, and to the Sioux quartzites of Iowa. The equivalence of the quartzites of Barron and Chippewa counties to the Sioux and New Ulm quartzites is to be inferred by the reader. These southwesterly exposures, like those in Wisconsin, are regarded as outcropping marginal portions of a quartzite belt extending, with some possible interruptions, through three or four States. The lithological characters of the quartzites of the several areas enumerated and their relationship to the Laurentian and the Paleozoic formations sanction their reference to the Huronian age. (Vol. IV, pp. 575–581.)

FIG. 3.—Section from Courtland to Pipestone, Minnesota. (After James Hall.)

a. Quartzites east of the Minnesota, at Redstone Ferry, dipping eastward. *b*. The outcrop of quartzites near the source of the Little Cottonwood dipping to the westward. *c*. The outcrop of quartzites at the Pipestone locality, dipping to the eastward. *d*. The interval between *a* and *b*, made by an eroded anticline which is now occupied by Cretaceous and more recent formations along this line. (An east-west section 40 miles north of this point shows the continuity of the Cretaceous formation interrupted by numerous prominences of Laurentian gneiss.) *e*. The lower country west of the Pipestone locality occupied by modern formations similar to *d*. R. Minnesota River. R′. Sioux River. The space between the two upper lines is intended to represent prairie formation. *f*. The place of the Pipestone stratum.

13. WINCHELL (N. H.). History of the Minnesota Valley. Minneapolis, 1882.

Chapter XXIX is devoted to the geology of the Minnesota Valley. This chapter is practically an epitome of Professor Winchell's observations in the Minnesota Valley in 1873, published in detail in the annual report of the Geological and Natural History Survey of Minnesota for that year. This report will be referred to in another place.

14. WINCHELL (N. H.) and UPHAM (Warren). The geology of Minnesota. Minneapolis, Vol. I, 1884, and Vol. II, 1888. Vols. I and II of the final report.

Mr. Upham's descriptions and field notes of the geology of the Minnesota River Valley are numerous and valuable. Special reference is here made only to the following topics and pages: Decomposed gneiss and granite (of Brown and Redwood counties) (p. 570), Potsdam quartzite (p. 572), the Eozoic rocks of Yellow Medicine County (p. 596), granite and gneiss of Lac qui Parle and Bigstone counties (p. 617), all in Vol. I; Archean rocks of Renville County (p. 194), Archean rocks of Chippewa County (p. 210), in Vol. II.

Further citations from Mr. Upham's writings will be made where the particular topics he writes upon are discussed.

SERIAL PUBLICATIONS.

15. Proceedings of the American Association for the Advancement of Science, Salem, Massachusetts, since 1848.

In an extremely interesting description of the Minnesota Valley during the Ice age, Warren Upham maintains (Vol. XXXII, 1883, p. 215) the ancient crystalline character of the underlying rocks of the Minnesota River Valley in these words: "In the 100 miles from Bigstone Lake to Fort Ridgely the strata are metamorphic gneisses and granites, which often fill the entire valley, 1 to 2 miles wide, rising in a profusion of knobs and hills 50 to 100 feet above the river."

In 1884, at the Philadelphia meeting, N. H. Winchell delivered the vice-presidential address in Section E on The Crystalline Rocks of the Northwest. In the grouping and correlation of these rocks the author says that "the outcrop of red granite near New Ulm, lying under the conglomerate and red quartzite, is probably the southwestward extension of 'the gabbro and red syenite at Duluth.'" These he calls the first group, i. e., the uppermost series of the crystalline rocks of the Northwest. (Vol. XXXIII, p. 364.) He further adds: "This group is represented by No. XX southwest of Lake Michigamme [in the upper peninsula of Michigan], by No. XX at Menominee [in Michigan and Wisconsin], and by Nos. 1 and 1*a* at Black River [in Wisconsin]."

16. Reports of the Chief of Engineers, U. S. Army, Washington, since 1866.

In the records of the work of the Corps of Engineers, United States Army, between 1867 and 1879, many facts of geological interest are stated and discussed. No engineer of the Army stationed of late years in the Northwest has taken a deeper interest in geologic and physiographic studies than Gen. G. K. Warren, after whom, "in honor and in memoriam," the River Warren has been named.[1] No one can fail to find profit in studying, from a geological standpoint, what General Warren has set forth regarding the physical features of the Mississippi and Minnesota river valleys and the history of their formation.

In his report for 1868 General Warren discussed the extensive erosion which the Upper Mississippi Valley has undergone, the evidences which this valley presents of a former elevation of the central part of the North American continent, and the almost entire lack of abrasion which the granite bed of the Minnesota River reveals in the upper part of its course (pp. 305–314). In 1873 a report was made of an "examination and survey of the Minnesota River above the mouth of the Yellow Medicine." The average fall of the stream, the character of the bluffs bordering it, and the location and extent of the lakes found along its course are given. The granite which occurs at the foot of

[1] Warren Upham, Proc. Am. Assoc. Adv. Sci., Vol. XXXII, 1883, p. 231.

Bigstone Lake is designated feldspathic (pp. 438, 439). In 1875–76 a very detailed report on the Mississippi River was published (Vol. II, Part L, pp. 381–451), containing "An essay concerning important physical features exhibited in the valley . . . and upon their signification." This valuable paper is illustrated by several maps and charts.

In 1878 the mature results of General Warren's labors appeared in the report on bridging the Mississippi River, containing several maps and diagrams. These results bear on the glacial origin of the Minnesota Valley, the existence of a glacial river, subsequently named River Warren by Warren Upham, and the occurrence of silted lakes between Ortonville and Courtland. They will be frequently referred to in subsequent pages.

17. The Minnesota Teacher, St. Paul, 1867-1875.

W. D. Hurlburt, a gentleman who has observed the geology of the State as his business carried him to various places, stated in this publication (Vol. IV, 1871), that "a band of granitic rocks forms the bed of the river [at Redwood Falls] similar to the exposures at Sauk Rapids and above [on the Mississippi River], and these indicate at once the shore line of the Azoic continent and the northern border of nearly all the sedimentary rocks in place in Minnesota" (p. 5).

18. The American Naturalist, Salem, Philadelphia, and New York, since 1867.

In Vol. II, 1868, an article by Gen. G. K. Warren, entitled, Certain Physical Features of the Upper Mississippi River, is discussed. The great excavation of the Minnesota River above Fort Snelling is cited, and the fact is stated that the bed of this river "for 110 miles below Bigstone Lake is partially granitic" (p. 497).

Emphasis is laid on the proposition that "the waters issuing from a lake have little abrading power, for they have comparatively little rubbing material to operate with.[1] Thus it was that the waters issuing at the old southern outlet of Lake Winnipeg (Lake Agassiz of Warren Upham) could make no impression on the granitic bed of the Minnesota. Had the granite been soft, like the Silurian rocks lower down in its course or like the Tertiary and Cretaceous rocks through which the Missouri has cut its way, then this part of the valley would have been worn away in the same manner, and we should have the drainage of all the Winnipeg Basin still to the southward. A cut of 400 feet at Bigstone Lake would have drained it, and the banks would then not have been as high as those of the Missouri at the Bijou Hills, which are 800 feet above the water of the river" (p. 500).

19. The Geological and Natural History Survey of Minnesota, Annual Reports, Minneapolis, since 1872.

Under this survey (still in progress) N. H. Winchell, State geologist, inspected the valley in 1873. The granites were held to be of a pre-

[1] Compare Geology of the Henry Mountains, by G. K. Gilbert, Washington, 1880, paragraph on Corrasion, p. 101.

vailing reddish color. That they are "schistose granites" is emphasized. The granite at La Framboise's place, described as a "type," is made up of the "ternary granite compound." The tendency to decompose into an impure kaolin, seen at Birch Cooley and Redwood Falls, is also mentioned. Since this material, provisionally called kaolin, prevails in the Cretaceous areas and is always present, so far as known, wherever the Cretaceous deposits have preserved it from disruption by the ice erosion of the Glacial period, its origin may be attributed to the action of the Cretaceous ocean. (Report for 1873, p. 163.)

20. The Minnesota Academy of Natural Sciences, Bulletins, Minneapolis, since 1873.

In Vol. III, Bulletin No. 1, Warren Upham has described (p. 151) a set of "maps showing the climate, geography and geology of Minnesota." In outlining the distribution of rocks throughout the State he says that the rocks of southwestern Minnesota are "mainly red quartzites exposed near New Ulm and thence westward to Pipestone and and Rock counties in the southwest corner of the State." The Archean system reaches from "the international boundary from the Lake of the Woods east to Lake Superior and extending thence southwest to the Minnesota River between Bigstone Lake and New Ulm, but terminating 20 or 30 miles southwest of this river" (p. 154).

21. Bulletins United States Geological Survey since 1883.

In Bulletin No. 8, on Secondary Enlargements of Mineral Fragments in Certain Rocks, R. D. Irving and C. R. Van Hise have discussed secondary enlargements of mineral fragments in certain vitreous quartzites (and sandstones) in the quartzite formation of southern Minnesota.

The similarity in character of these quartzites to the Huronian quartzites of the Baraboo district of Wisconsin, and to much of the quartzite of the Huronian of Lake Huron is pointed out. "At Redstone [Courtland] the transitions from argillaceous, reddish sandstone to completely vitrified, brick-red to purple quartzite, and from these again to completely loose sandstones, are frequent and abrupt." The fact is also emphasized that "over considerable areas the appearance is as if the rock at the higher levels had been vitrified by exposure." (P. 34.) Yet the appearance of the quartzite in the railway cuttings and elsewhere suggests the possibility that this vitrification may be due to the descent and spreading of a silica-bearing solution (p. 34).

22. The Geological and Natural History Survey of Minnesota, Bulletins, Minneapolis, since 1887.

23. The American Geologist, Minneapolis, since 1888.

CHAPTER III.

GEOGRAPHICAL DISTRIBUTION AND GENERAL CHARACTERS OF THE ROCKS OF THE MINNESOTA RIVER VALLEY.

Before proceeding to a detailed description of the crystalline rocks under discussion, a résumé of their geographical position will be given, and the general characters of these rocks, more especially with reference to their structural relations and peculiarities of texture, will be outlined.

In passing up the Minnesota River from its mouth at Fort Snelling to South Bend a southwesterly course is followed, the river flowing in a northeasterly direction. The river runs through a troughlike valley, whose walls, partly of Cambrian dolomite and sandstone and partly of glacial débris, reach a height of 200 to 250 feet. These walls are from 1 to 4 miles apart.[1] At South Bend a right angle is turned, to which the river comes down from the northwest. Near this point the volume of the stream is enlarged by the addition of streams of some size flowing in from the south. Along the banks of one of these streams, the Lesueur, the explorer of that name found deposits of copper ore, from which quantities were sent to France for assay in the year 1700. Continuing up the river, it is not until T. 109 N., R. 30 W. is entered that any crystalline rocks are found. This area of crystalline rock is called the Courtland district, from the township of that name.[2]

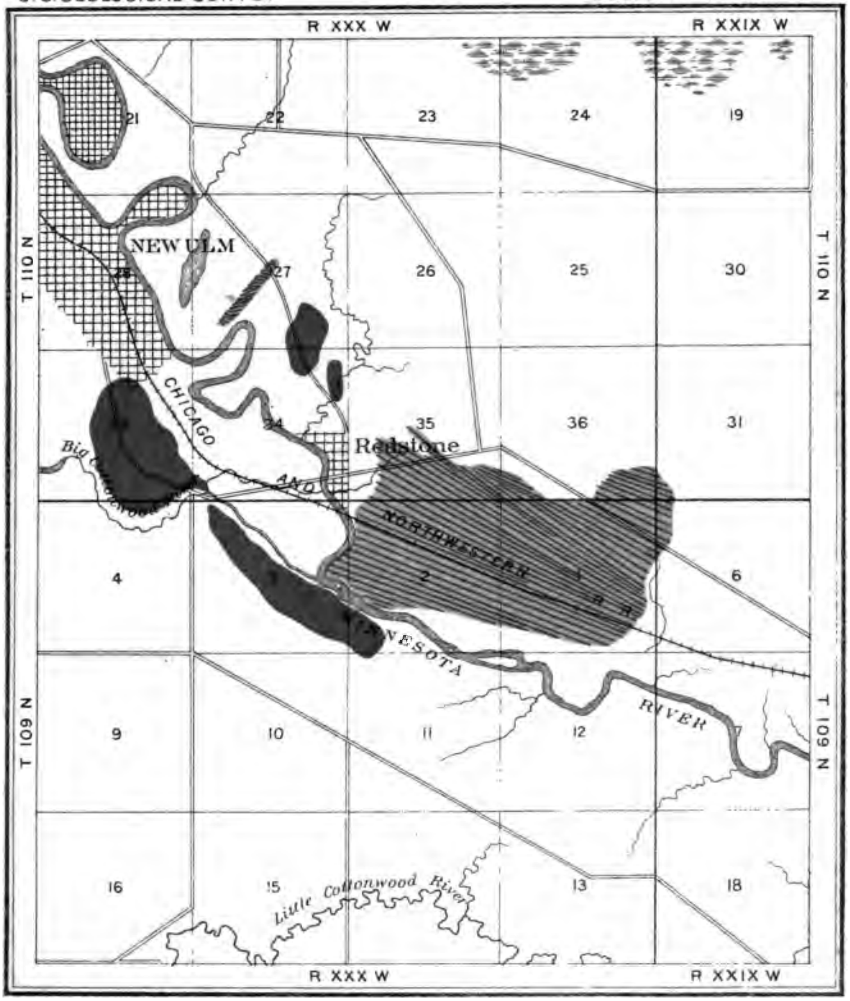
COURTLAND DISTRICT.

QUARTZITE EXPOSURES.

The pre-Cambrian rocks first found in passing up the Minnesota River Valley are red quartzites (see Pl. II) with associated quartzite conglomerates and sandstones. These exposures have been visited by nearly all the geologists and explorers who have traversed the Minnesota River Valley. The rocks are not continuously bare from the river to the summits, but lie exposed in a series of terraces. In a rough way these terraces show different phases of rock structure and texture. Probably 50 feet represents the greatest thickness of strata shown at any one place. So far as has been seen, the outcrops lie wholly on the north side of the Minnesota River. The Cottonwood

[1] The Minnesota Valley in the Ice age, by Warren Upham: Proc. Am. Assoc. Adv. Sci., 1883, p. 216.

[2] Report intended to illustrate a map of the hydrographical basin of the Upper Mississippi River, by *J. N. Nicollet;* dated February 16, 1841: Twenty-sixth Congress, second session, Senate Doc. 237, p. 18.



GEOLOGICAL MAP OF THE COURTLAND DISTRICT

Scale

1 0 1 2 MILES

CRETACEOUS QUARTZITE GRANITE AND GNEISS

JULIUS BIEN & CO. LITH. N.Y.

River enters the Minnesota directly south of the locality. With its power for erosion this stream would have laid bare any high masses of quartzite lying between the elevated bluffs that bound it on either side.

Exposures near Redstone.—The exposure southeast of Redstone, in secs. 1 and 2, T. 109 N., R. 30 W., and secs. 35 and 36, T. 110 N., R. 30 W., is an extensive one. Here many steps can be seen in the transition from a loose, argillaceous and shaly sandstone to a vitreous quartzite; and again, from a vitreous quartzite of fine and uniform texture to a coarse quartzite conglomerate. The sandstones occupy the lower beds of the exposures, and the vitreous quartzite and quartzite conglomerates the higher beds. Yet there are no sharp divisions, many alternations of sandstone and quartzite layers occurring. The railroad cuts which penetrate these rocks 30 feet or more show that the quartzite is interbedded with the sandstone, and that the induration is not wholly a surface phenomenon.[1] There is a gradual ascent of the surface in passing away from the river, varying from 1 to 25 degrees, and many depressions bear evidence of unequal erosion, due to the unequal hardness of the rock, resulting in the terraces mentioned.

The highest portions of these exposures must be at least 175 feet above the Minnesota River. The erosion of the upper 50 feet is unquestionably due partly to glacial action, as grooves and striæ, still sharp and clear, show the direction of the ice currents, which, for this locality, was S. 33° E. But at places up to 125 feet above the point at which the lowermost shaly sandstone layers pass under the river, potholes and narrow tortuous grooves are numerous. This peculiar surface is clearly the result of the wear of running water rather than of moving ice; so the conclusion must be that the river's bed was once high up in this exposure, and that a large, muddy stream, with a rapid current, cut the gorges, gouged out the softer layers, wore the potholes, and chiseled into great irregularity the whole surface of the harder quartzite.

It is implied, in the statement of these erosive phenomena, that the wear of the rocks from the terrace 125 feet above the river down to the present water level has occurred since the Glacial period closed for this locality. That it has been accomplished since Cretaceous time is evident from the erosion of Cretaceous rocks in the neighborhood and within this same river gorge. The height mentioned, viz, 125 feet, certainly suggests the upper limit of erosion by water alone, and thus of post-Glacial work. The rocks are too hard to admit of rapid erosion.[2] The more complete preservation of the marks of

[1] On secondary enlargements of mineral fragments in certain rocks, by R. D. Irving and C. R. Van Hise: Bull. U. S. Geol. Survey No. 8, 1884, p. 34.

[2] Compare The recession of the Falls of St. Anthony, by N. H. Winchell: Geol. Nat. Hist. Survey Minnesota, Vol. II, 1888, pp. 313–341; The place of Niagara Falls in geologic history, by G. K. Gilbert: Proc. Am. Assoc. Adv. Sci., 1886, p. 222; Man and the Glacial Period, by G. F. Wright, 1892, pp. 361, 362; and many others.

water wear on the lower terraces may be due to the protection against glaciation afforded by the shelving rock surfaces which confronted the river gorge while the ice masses were pushed over them; yet the stronger probability is that this condition marks the stage of erosion when the final ice retreat passed this point. A recent study of the Dalles of the St. Croix by Berkey shows that a post-Glacial work has been accomplished by the St. Croix River[1] even greater than that at Courtland, both in its extent and in its significance as a measuring rod to apply to post-Glacial time.

In general the strike of the quartzites is N. 60° to 70° W., and their dip varies from 5° to 27° N. These figures are the average of a large number of observations in different portions of the area. There is considerable variation both in strike and in dip, even within restricted areas. The dip is more marked in the lower beds—those near the edge of the river—than in the uppermost beds now visible.

All the rocks have very high silica content. Often, indeed, they seem to be wholly silica, except for a small quantity of ferric oxide and calcium phosphate in the cement, solidifying the grains of clear quartz sand into a nongranular rock. Noting that Prof. James A. Dodge found distinct traces of calcium phosphate in the supposed new fossil, *Lingula calumet*, discovered[2] by Winchell in 1885 in the catlinite interbedded with the red quartzite of Pipestone, Minnesota, a rock universally conceded to belong to the same horizon as this quartzite at Courtland, Mr. E. J. Babcock, now of the University of North Dakota, made tests for calcium phosphate in the Courtland quartzites. Five samples, showing no traces whatever of fossils, were taken from as many different parts of these rocks, representing the shale, the sandstone, the indurated quartzite, and the conglomerate of these beds, and qualitative analysis in all cases showed distinct traces of calcium phosphate. Some of them, and notably a sample of the conglomerate from near the top of the hill—that is, from the uppermost layers of quartzite exposed—yielded a very appreciable amount.

Microscopically, also, the quartzites show considerable diversity. The fine vitreous quartzite, as stated by Irving and Van Hise,[3] shows the original fragmental grains coated with a film of oxide of iron and then enlarged, the cementing material becoming a constituent part of the reconstructed angular grains. In other places the indurating material is deposited independently as cryptocrystalline, partially chalcedonic quartz, with no regular orientation. There are still other places in which there seems to have been a cutting down of the original grains and the formation of a cryptocrystalline groundmass inclosing scattered and corroded grains of quartz. These latter places appear to be confined to the surface portions of the exposure

[1] Geology of the St. Croix Dalles, by Charles P. Berkey: Am. Geologist, Vol. XX, Dec. 1897, p. 368.

[2] Notice of the discovery of Lingula and Paradoxides in the red quartzites of Minnesota, by N. H. Winchell: Bull. Minn. Acad. Nat. Sci., Vol. III, Pt. I, 1889, p. 103.

[3] *On secondary enlargements of mineral fragments in certain rocks*, by R. D. Irving and C. R. Van *Hise: Bull. U. S Geol. Survey No. 8*, 1884, pp. 34, 35.

RELATION OF THE GNEISSIC SERIES TO THE BASAL CONGLOMERATE NEAR NEW ULM.

along the bedding planes and on the sides of the vertical joints, which have served as channels of percolation for subterranean waters. The silica thus dissolved and removed has doubtless acted as the indurating material for the underlying layers.

Exposures near New Ulm.—In sec. 27, T. 110 N., R. 30 W., near New Ulm, 1½ miles northwest of the exposures near Redstone just described, lie large outcrops of coarse quartzite conglomerate. The strike and dip are nearly at right angles with the strike and dip of the quartzite southeast of Redstone; the strike near New Ulm, as roughly represented by the direction of the exposure, being N. 15° E., with a dip varying from 10° to 15° SE.

This rock is figured by Professor Irving, in his classic paper on Classification of the Early Cambrian and pre-Cambrian Formations, as an exposure of a typical basal conglomerate.[1]

There is much variation in the coarseness of the pebbles, all sizes, from average sand grains to bowlders 10 to 12 inches in diameter, being seen. These pebbles consist almost entirely of quartz, in part dull-red or brown jasper and in part clear white quartz. No quartzite masses were noticed possessing the characters of the quartzite southwest of Redstone, nor were any granitic pebbles seen.[2] This is somewhat surprising, in view of the close proximity of the granitic and gneissic rocks of the valley.

PROBABLE CONTINUATION OF THE QUARTZITE IN SURROUNDING AREAS.

There is evidence that the Courtland quartzites underlie a considerable belt of territory. Around Swan Lake (see Pl. I), from 4 to 6 miles northeast of the exposures near Redstone and New Ulm, bowlders of red quartzite strew the ground in places. In Cottonwood and Watonwan counties, about 25 miles to the southwest, many square miles are underlain by vitreous quartzites, and many broad surfaces appear, representing a thickness of strata of at least 1,500 feet. The formation is, therefore, several times as thick as at Courtland, there being exposed at the latter place from 250 to 300 feet only.[3] There is no doubt that the extensive exposures of red quartzites in Rock and Pipestone counties, Minnesota, and in many counties of southeastern South Dakota, belong to this same formation.[4]

To the eastward little is known of the extension of these beds. At Minneopa Falls, near Mankato, is a well 1,000 feet deep. In boring, at 575 feet from the surface a conglomerate was reached with pebbles of clear, fine, nongranular quartzite up to 2 or more inches in diameter.

[1] Seventh Ann. Rept. U. S. Geol. Survey, Pl. XLIV, facing p. 430.

[2] Compare paragraphs in Geology of Sibley and Nicollet counties, by Warren Upham: Geol. Nat. Hist. Survey Minnesota, Vol. II, 1888, pp. 157–160.

[3] Preliminary paper on an investigation of the Archean formations of the Northwestern States, by R. D. Irving: Fifth Ann. Rept. U. S. Geol. Survey, 1884, p. 201.

[4] Notes upon the geology of some portions of Minnesota, etc., by James Hall: Trans. Am. Philos. Soc., Phila., Vol. XIII, N. S., 1865, p. 338.

From this depth to more than 800 feet below the surface the borings consisted chiefly of quartzite pebbles indistinguishable in macroscopic and microscopic characters from the vitrified quartzites at Courtland.[1] These pebbles are essentially different from those composing the "basal conglomerate" beds opposite New Ulm.

In 1897, at Glencoe, about 35 miles north of Redstone, a well, bored for water, yielded drillings of a decidedly red color between depths of 936 and 1,640 feet. The rocks there penetrated were probably the northward extension, beneath the Paleozoic, of these Courtland quartzites.

AGE OF THE QUARTZITE.

The occurrence of the quartzite conglomerate at Minneopa Falls establishes the fact that the great Sioux quartzite terrane was thoroughly indurated and a subject of extensive erosion at the time the bottom beds of the Middle Cambrian were being laid down in the area now embraced in the Upper Mississippi Valley. (See fig. 4.)

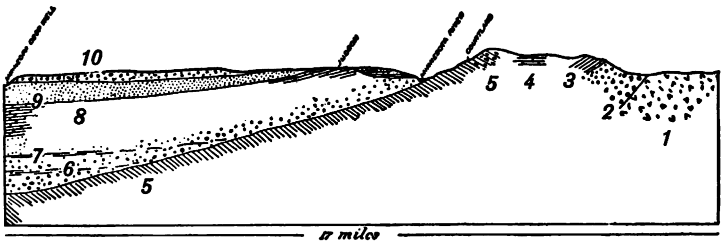


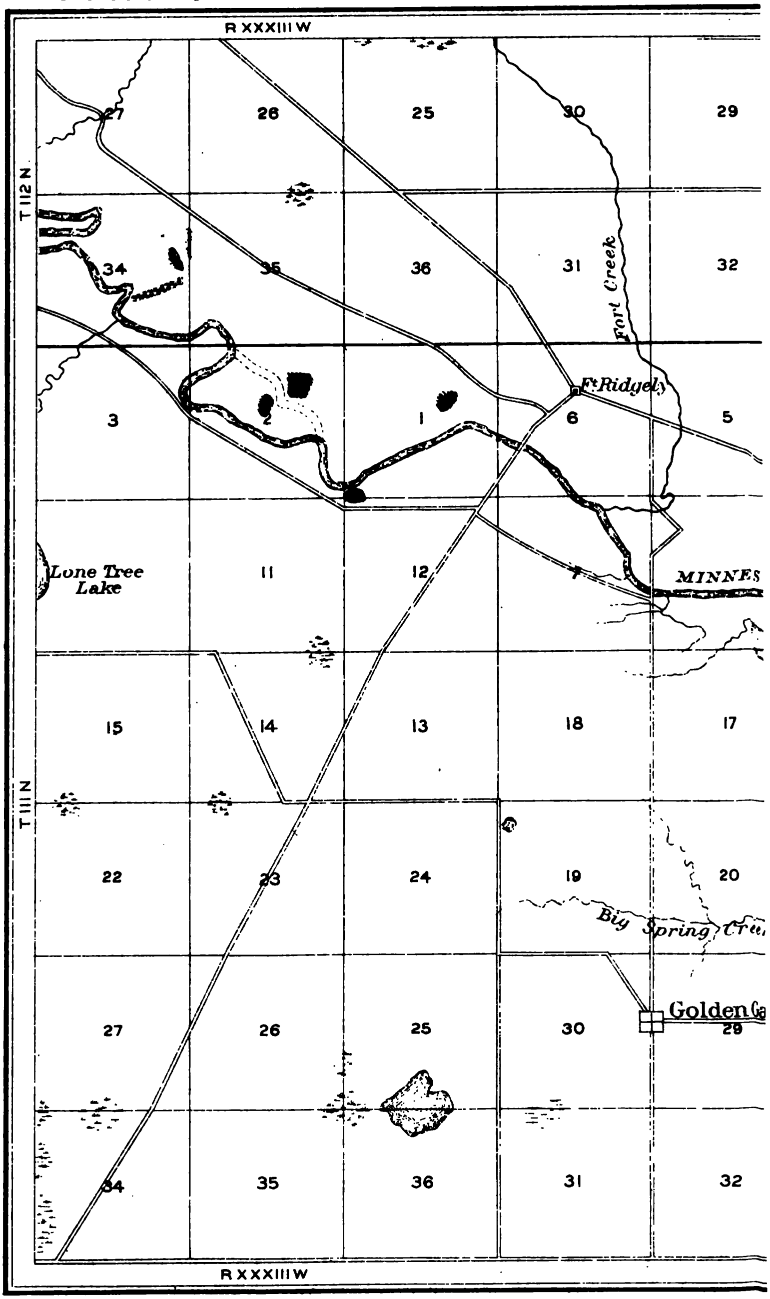
FIG. 4.—Hypothetical section from Courtland to Minneopa. 1, Granite-gneiss of the Minnesota River Valley; 2, Conglomeratic base of the quartzite formation; 3, Quartzite conglomerate much finer than at the base; 4, Concretionary Cretaceous limestone; 5, The Courtland exposures of red quartzite, with overlying conglomeratic phases; 6, Cambrian conglomerate with pebbles of red quartzite; 7, Dresbach (?) sandstone; 8, St. Lawrence dolomites and shales; 9, Jordan sandstone, seen at Minneopa Falls; 10, Glacial drift of varying thickness.

The lapse of an enormous interval of time between the deposition of the quartzites and the Middle Cambrian (Potsdam) is most strikingly shown by Irving for the Baraboo district of central Wisconsin, a district presumed by that writer to show features of age and stratigraphic relations identical with those of the Courtland district of southwestern Minnesota.[2] Whether these quartzites belong to the Upper Huronian subdivision of the Algonkian can not be determined from the mere fact of their lying unconformably beneath the Middle Cambrian. It is sufficient, for our present purpose, to know that a time gap of great length intervened between the deposition of these great quartzite beds and the close of the erosion which partly removed them and accumulated their débris as masses of conglomerate pebbles in the bottom layers of the Paleozoic of the Upper Mississippi Valley.

[1] The deep well at Minneopa, Minnesota, by C. W. Hall: Bull. Minn. Acad. Nat. Sci., Vol. III, No. 2, 1891, p. 248.

[2] On the classification of the early Cambrian and pre-Cambrian formations, by R. D. Irving: Seventh Ann. Rept. U. S. Geol. Survey, 1886, p. 403 et seq.

U. S. GEOLOGICAL SURVEY



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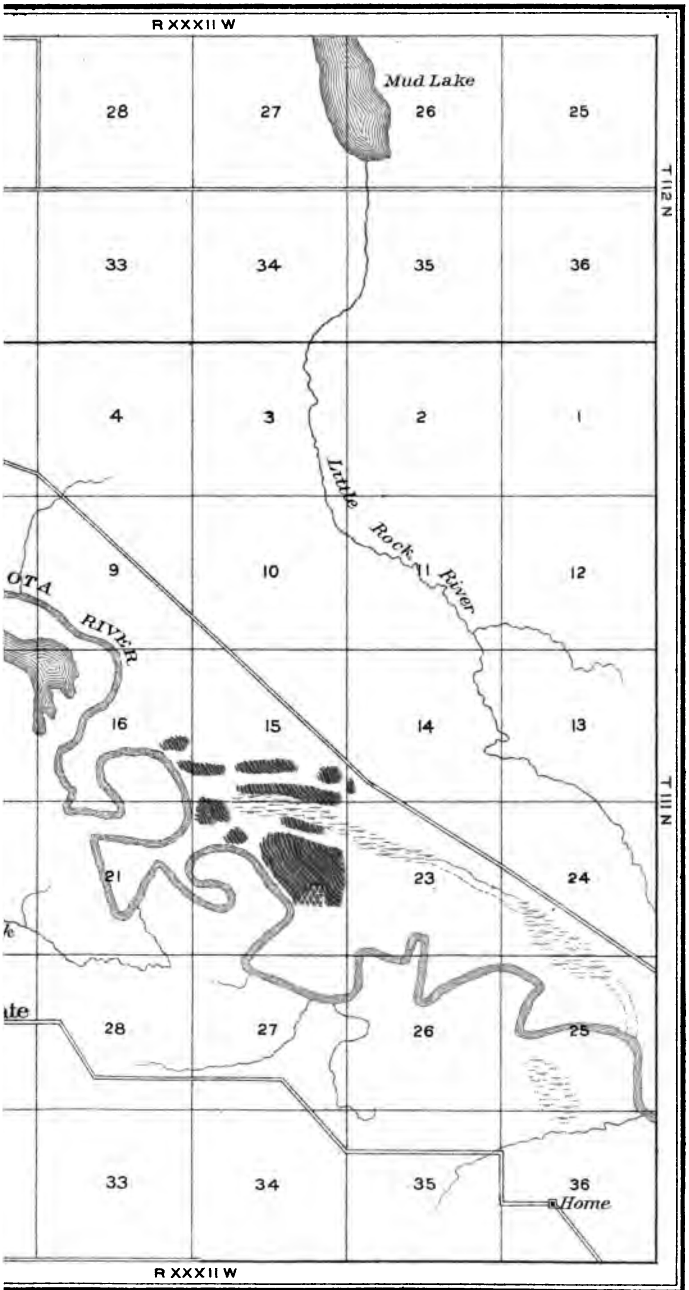


JULIUS BIEN & CO. LITH N.Y.

)RT RIDGELY DISTRICT

1 2 MILES

GRANITE AND GNEISS

GNEISSOID GRANITE EXPOSURES.

One hundred and fifty paces west of the New Ulm conglomerate, and undoubtedly extending beneath it, lies the first outcrop of gneiss that is reached in ascending the Minnesota River Valley. Three or four knobs stand some 5 to 15 feet above the level of the river bottom. The several outcrops are shattered into numerous loose blocks by the forces of weathering. These blocks are so disintegrated and crumble so readily that hand specimens can with difficulty be shaped. They show all the phenomena of concentric weathering so common in disintegrating granites of coarsely crystalline texture. The shattered condition precludes the possibility of noting the strike or dip of the laminæ. No contortion can be seen. The rock is granitic in texture, of medium coarseness, somewhat porphyritic, and of a reddish color, due to the abundance of red feldspars. It is hornblendic, but contains only a small portion of basic constituents and a much less proportion of quartz than the exposures farther up the river. The feldspars are orthoclase, microcline, and oligoclase, and are all considerably altered through kaolin, the orthoclase and the oligoclase to a much greater extent than the microcline. The altered areas are heavily charged with hematite and brown ferrite. The deepest specimens obtainable along the planes of fracture show a lodgment of ferric oxide, which in places is apparently hydrous (limonite). This lodgment is especially interesting around nests of basic constituents. In such places the intermingling of the brown and green gives a particularly weathered appearance, which is not, however, fully borne out by the microscopic examination.

FORT RIDGELY DISTRICT.

Passing up the river a distance of 15 miles from New Ulm, La Framboise's place is reached. This spot marks the beginning of some very extensive exposures of rocks. Here they come down to the water's edge, forming a good canoe landing and marking the spot where one of the earliest trading posts of the valley was located by the father of the present owner of the place.

GNEISSOID GRANITE.

Area northeast of Golden Gate.—In the area northeast of Golden Gate (Pl. IV), scattered over several sections in the vicinity, particularly over secs. 14, 15, 16, 21, 22, and 23, T. 111 N., R. 33 W., are many exposures of a gneiss which to a considerable extent is augitic and granitoid. It varies in texture, and over much of the area is so greatly shattered as to be unfit for systematic quarrying. Occasional areas are rather coarse, orthoclase crystals 5 or 6 inches in length being found, and in other areas a fineness unusual in gneissic rocks can be seen. As a rule, these exposures exhibit a rock of red color, but this color shades through pink to a dirty gray, and in some of the

exposures the last-named color is the predominant one. The more finely granular modifications are those of the gray color, and these carry augite. In all the rocks of this locality there is an unusual lack of biotite. Often hand specimens may be found on which not a folium of this mineral can be seen. The quartz is rather opalescent. The gneisses, as a whole, are characterized by a high per cent of silica.

Area west of Fort Ridgely.—West and southwest of old Fort Ridgely the gneiss assumes a darker color and a more pronounced gneissic habit through the increase of the biotite and the hornblende. It seems much fresher, and in places some quarrying has been done.

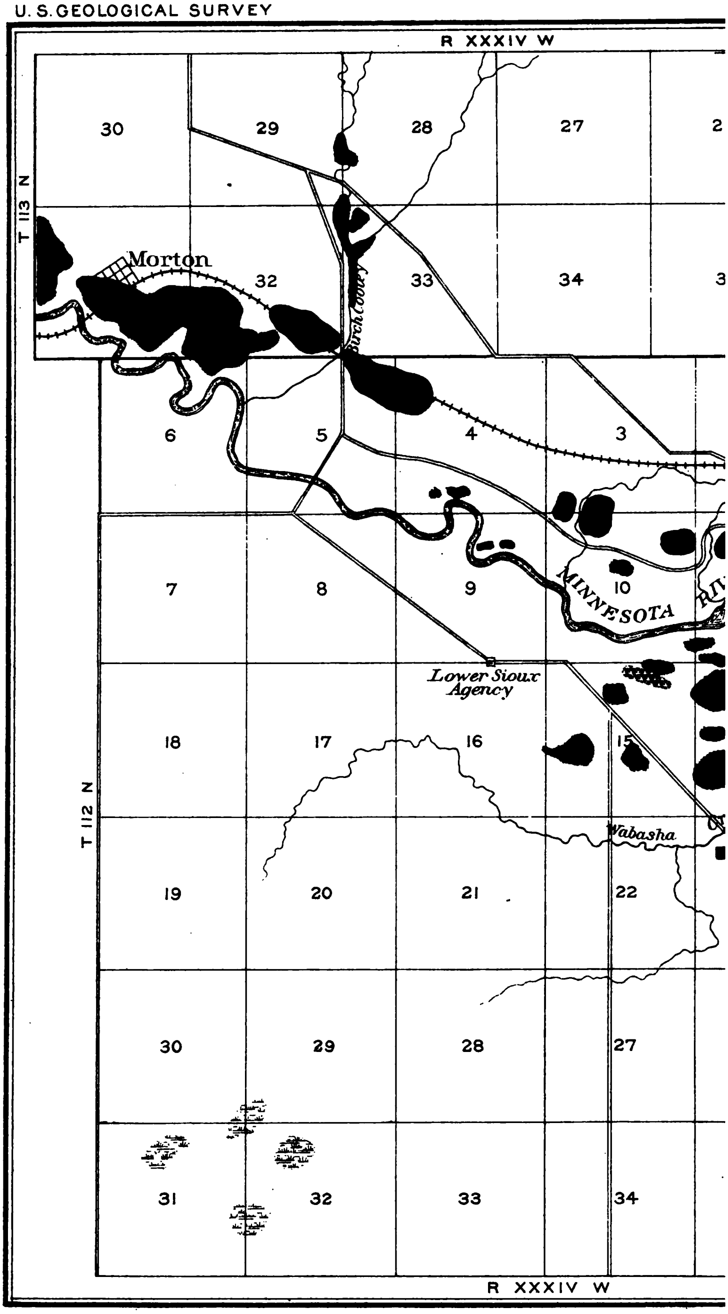
Along the south side of the river, within the area of the map (Pl. IV), several exposures of gneissic rocks are said to occur. The one locality visited was the old quarry out of which material was secured by the Government for erecting the barracks and other buildings of Fort Ridgely, whose ruins now stand upon a conspicuous morainic bluff on the north side of the river, 1½ miles distant from the quarry. The location of this outcrop is at a sharp bend in the river, 150 paces N. and 1,900 paces W. of the southeast corner of sec. 1, T. 111 N., R. 33 W. It is 200 paces long by 150 paces wide. The rock is medium-grained gneissoid granite, porphyritic in texture, and is somewhat stained at the surface by weathering and the infiltration of ferric oxide along secondary structures. It is somewhat shattered, and in places is decidedly granitoid. The more laminated portions show some contortion of the bands, which have a general N.-S. strike, with a westerly dip of from 40° to 50°. In these respects the rock agrees with the masses on the north side of the river in secs. 35 and 36, T. 112 N., R. 33 W.

BASIC ROCKS.

In sec. 34, T. 112 N., R. 33 W., is a fine exposure of augite-schist. It can not be certainly determined whether it is a dike breaking through the gneiss or an interbedded layer of quite different mineral and chemical composition from the associated gneissic rocks, although it is probably the former. Only a few hundred paces northeast of the schist is a highly altered rock, now bearing epidote and calcite, which in both external and internal characters gives strong evidence of having once been an olivine-gabbro.

Near La Framboise's a hornblendic hypersthene-gabbro occurs in the augitic granitoid gneiss, and at the old Fort Ridgely quarries, NW. ¼ of NE. ¼ sec. 2, T. 111 N., R. 33 W., a hornblende-biotite-schist can be seen which doubtless was once similar in mineral composition to the hypersthene-gabbro at La Framboise's. It is probable that the gabbro just mentioned occurs as an intrusion in the gneiss. The contact between the two is sharp and clear where a wall is uncovered for a few paces.

Everywhere in the rocks of the Fort Ridgely district there are veins of quartz, and in places they are very numerous. For example, in sec.



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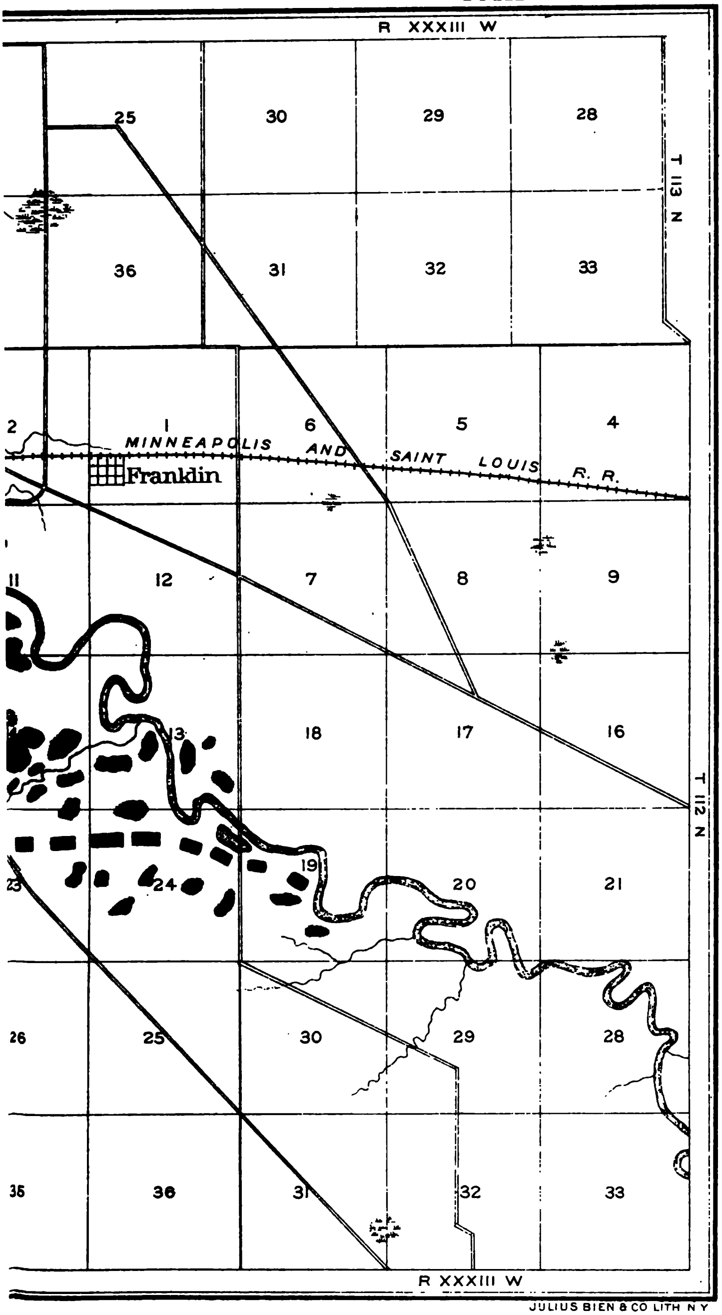

JULIUS BIEN & CO LITH N Y

E MORTON DISTRICT

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IO AND GABBRO-SCHIST GRANITE AND GNEISS

2, T. 111 N., R. 33 W., running in a prevailing NW.-SE. direction, veins of milky quartz, varying in thickness from that of paper to 5 inches across and lenticular in shape, are seen to variegate the surface of the rock. Schistose inclusions are not infrequent. These possess a medium texture and vary somewhat in mineral composition.

MORTON AND BEAVER FALLS DISTRICTS.

PRE-CAMBRIAN ROCKS.

Lower Sioux Agency area.—In secs. 10, 11, 13, 14, 15, 23, and 24, T. 112 N., R. 34 W., on the south side of the Minnesota River, occur mound after mound of gneissic rocks, cut by diabase dikes and associated with altered gabbros and peridotites. In texture the gneissic exposures vary somewhat. On the average, the rocks are medium grained, but in places orthoclase individuals 4 inches across are found. Considerable contortion was noted in the lamination, but the general direction is NE.-SW. The number of veins and segregations is less than around Fort Ridgely. The gneiss adjacent to the large diabase dikes is of unusual freshness. This freshness seems to be an accidental character, for northwest of these exposures, in sec. 15 of the same township, the gneiss is badly weathered. This weathering and the already existing jointing of the rocks produce concentric blocks of various sizes, the uppermost and oldest being the most spheroidal. The gneisses are of the normal hornblendic biotite type. Accessories rather widely found in granitic rocks occur, particularly apatite, pyrite, and magnetite.

On the Tracy farm, in sec. 10 of this same township, a beautiful chloritic gneissoid granite is found, not in large quantity, but with beautiful areas of radiated chlorite and chlorite plates in vermicular chains. (Pl. XVII, *A*.) This rock carries many inclusions of a dark-green color, which show a predominating quantity of chlorite.

In sec. 14 of the same township are large masses of a coarse-grained, dark-colored, hornblendic rock. There is a foliation in a general NE.-SW. direction and a southeasterly dip of 80°, although at the surface there is much contortion. This is evidently an altered gabbroid rock.

In sec. 19, T. 112 N., R. 33 W., and secs. 23 and 24, T. 112 N., R. 34 W., lies the largest clearly defined dike, save the one at Pigeon Falls, which the writer has seen in Minnesota.[1] Its width is 60 paces, and it can be traced 2 or 3 miles across the valley, standing in the midst of a large mass of fine, fresh, gray gneiss. In composition it is a badly altered quartzose diabase.

In sec. 15, associated with the gneiss, is a hornblende-augite-schist which contains some hypersthene.

[1] This dike, crossing the Pigeon River and forming the falls named, has been described by Norwood in Owen's Report of a Geological Survey of Wisconsin, Iowa, and Minnesota, etc., Philadelphia, 1852, p. 405; and has been referred to by Irving in The copper-bearing rocks of Lake Superior: Mon. U. S. Geol. Survey, Vol. V, 1883, p. 371.

In sec. 9 of the same township occur the only peridotite and serpentine seen in place in the Minnesota River Valley. Two low knobs, each 100 paces long, 50 paces wide, and not exceeding 10 feet in height, represent all of these rocks. The variety of peridotite seems to be saxonite, although somewhat altered. The numerous cavities in the rock are filled with geodized incrustations of amethystine quartz and, more rarely, resinous-looking calcite.

In the more exposed portions the alteration mentioned has proceeded until the original constituents have wholly disappeared. Indeed, a set of rock sections may be prepared showing every degree of alteration from a nearly normal peridotite, with only slight alteration of its enstatite and olivine, to a serpentinous rock in which not a trace of the original constituents remains.

While these knobs of peridotite are the only occurrence of the rock undoubtedly in place, it may be added that in secs. 32 and 33, T. 112 N., R. 33 W., between the foot of the morainic bluff and the present bed of the river, stands a terrace in which are many bowlders of peridotite and serpentine. The present condition of these bowlders points to the probability that they have been transported but a short distance, thus leading to the inference that beneath the glacial drift and the

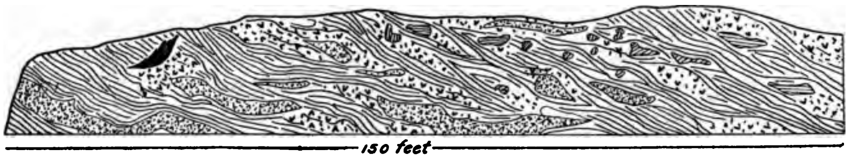
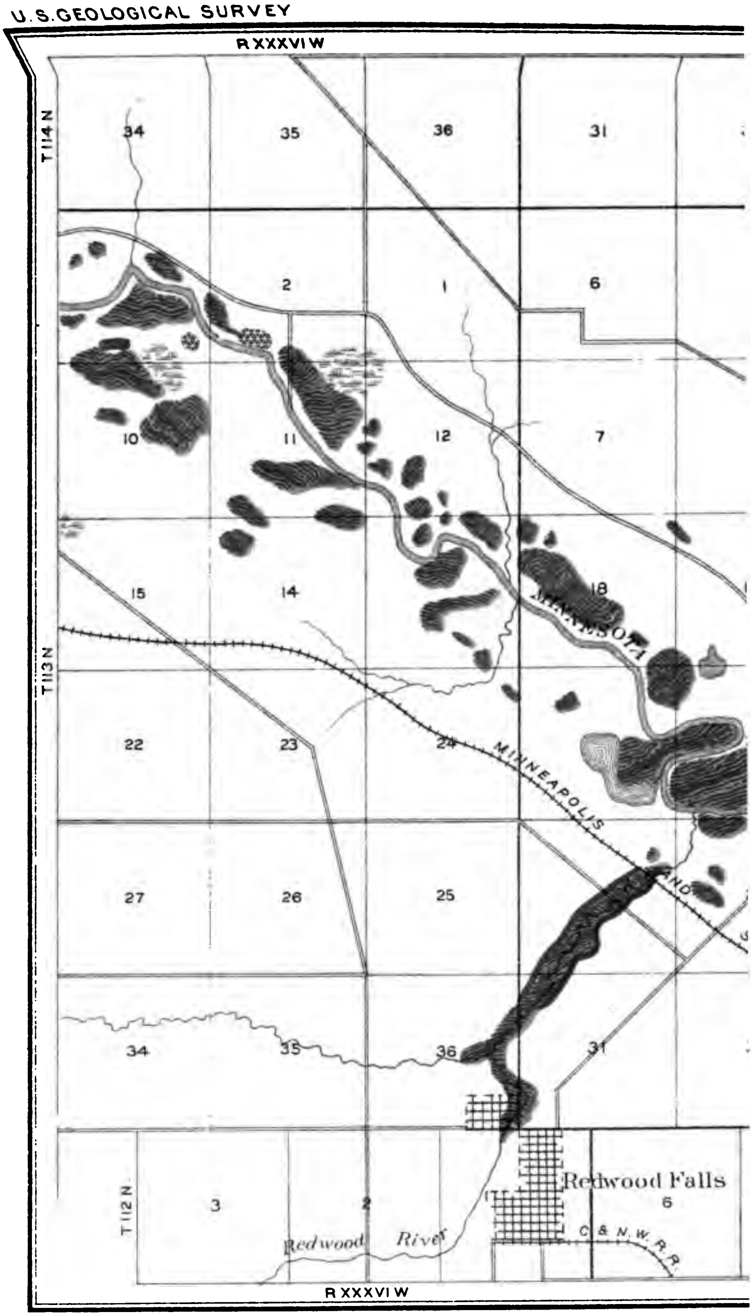


FIG. 5.—Contorted hornblende-biotite-gneiss, from railway cut at Morton, 150 feet long.

deposits of river débris there lies a large mass of these hea basic rocks. Every petrological character is identical with the corresponding one of the rocks in situ in sec. 9, already mentioned.

Morton area.—At Morton appear huge mounds of gneiss with a contorted lamination. (Fig. 5.) This gneiss is hornblendic, and has a prevailingly dark color. In places nests of pyrite can be seen on freshly fractured surfaces. In coming up the river from La Framboise's to this place we see a gradual change in the color of the gneissic rocks from a reddish to a prevailingly dark gray, a change from the granitoid structure to the gneissic, a disappearance of the augite-bearing rocks lean in basic minerals, and the appearance of nonaugitic gneisses in which both hornblende and biotite are abundant. The foliation of these rocks in all its contortions can be seen on the surface wherever weathering has not so corroded it that part of the constituents are no longer visible. The railroad cut at Morton shows a fresh surface. The accompanying figure (fig. 5) was taken from the west side of that cut. Attention may be called to the coarsely crystalline masses of pegmatite which are rather thickly distributed throughout this fresh Morton gneiss. These masses are not so clearly defined as are pegmatitic



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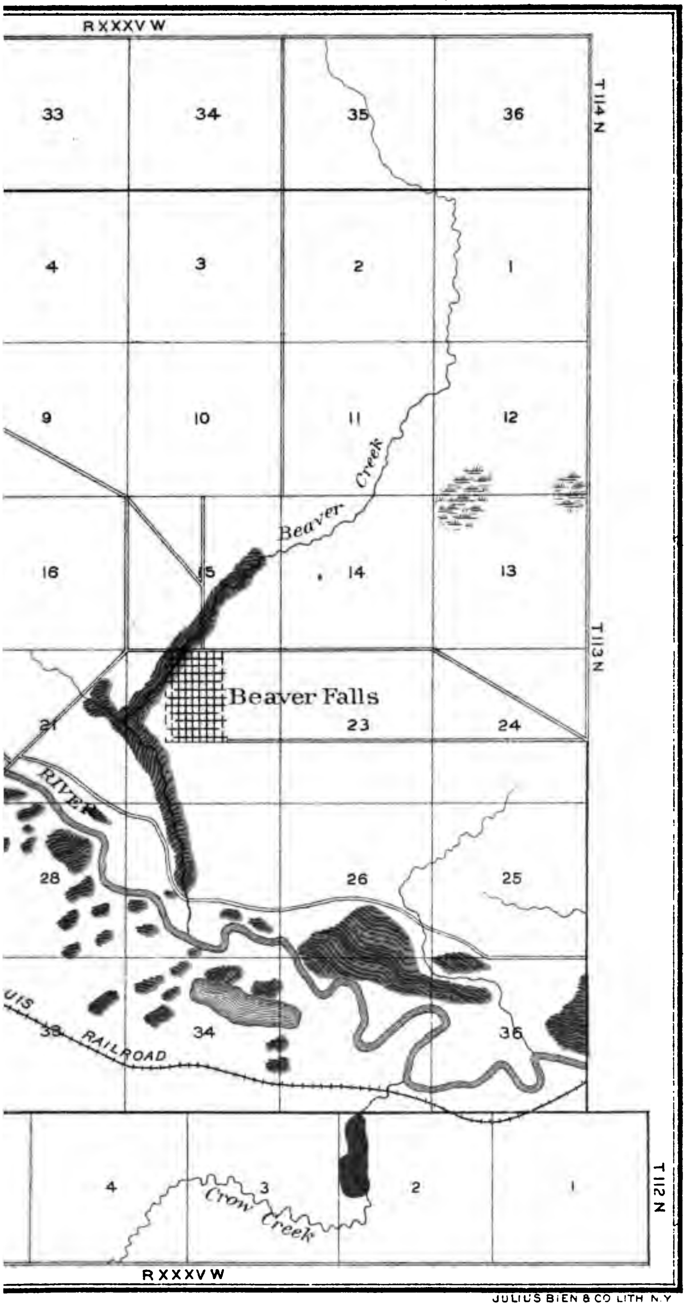

JULIUS BIEN & CO. LITH. N.Y.

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GRANITE AND GNEISS

veins, but their general characters indicate them to be such. In almost all cases noted they merge insensibly into the normal gneiss. In places they carry nests of biotite and hornblende, many of which are 1 or 2 inches across.

Veinlike segregations of feldspar and quartz and of quartz alone are everywhere numerous. They are not marked by unusual size, nor by the occurrence of metallic contents. There is no little diversity, however, in mineral constituents, as well as in texture and structure. On Birch Cooley some finely textured reddish veins of true granitic type show a distinctly laminated structure. They are irregular in shape and direction. Elsewhere a pegmatitic structure prevails. In the altered portions of the gneissic rocks the veins, which are also altered, carry numerous scales and pockets of limonite. These altered veins show much variation in color and texture. In many large areas, where the color is pink or reddish gray the feldspars are abundant, and where reddish black the biotite and hornblende occupy a larger place than usual. These characters are particularly noticeable at the exposures in secs. 29 and 30, T. 113 N., R. 35 W., north of the city of Redwood Falls.

The tops of the large mounds of gneiss at Morton, 75 feet above the high-water mark of the present Minnesota River, display indubitable evidences of water erosion. For the most part these surfaces are smooth and rounded, but on the very top of the highest hill a pothole of considerable size still exists. Grooves cut by running water can also be seen.

At Morton (Pl. V) the gneiss is, in places, remarkably fresh. Ordinary metamorphic changes, as Geikie defines the term,[1] are everywhere met with among these rocks. In a few places changes are noted which can be traced directly to surface influences; also changes which have removed so much of the rocks that what is now left has every character of an entirely different species. The kaolin beds of the Birch Cooley Gorge are a case in point, because there is no doubt that these beds are altered gneissic rocks which at one time presented characters similar to, if not identical with, those of the gneisses at Morton which are now so fresh and firm. There is little doubt that the Birch Cooley exposures are portions of the same beds that appear at Morton.

Beaver Falls area.—(Pl. VI.) Along the bottom lands of the Minnesota River, northwest of Morton, the gneissic rocks appear in large, high knobs. The higher and more exposed portions of these outcrops are comparatively fresh and firm, while in the more sheltered places the kaolinized portions are not yet removed. A distinctly gneissic habit prevails, with less contortion than appears around Morton. The strike of the laminæ is NW.-SE., and the dip is NE., with a varying angle. While in general there is little difference in character between

[1] Text-book of Geology, by Archibald Geikie, 3d ed., 1893, p. 595.

the gneiss of the knobs between Morton and Beaver Falls and the quarried rocks of Morton, slight differences may be noted. The porphyritic character of the gneiss at Beaver Falls is rather prominent. Feldspar crystals, orthoclase and microcline, are well defined. In size they reach a length of 2 or more inches. They show Carlsbad twinning, are much fresher than the finer-grained matrix, and resist weathering to such an extent that they stand out from the surface of the rock a half inch or more. Their whitened aspect indicates the kaolinized condition which even the freshest individuals exhibit. The gneissic, porphyritic condition which has just been noted is not uniform. In places a pegmatitic structure covers extensive areas. These coarser phases are at times sharply defined, and again pass gradually into the normal biotitic gneiss of the area. In some areas finer granitic veins are frequent, similar in texture, color, and mineral composition to those seen on Birch Cooley Creek, in the Morton district, penetrating the fresher phases of the gneisses.

The surface material of the gneisses shows no appreciable amount of hornblende, almost all of the basic portion being biotite.

Joints are everywhere very conspicuous upon these mounds. In places they have produced nearly perpendicular walls. This is not noticeably the case on the southerly face of the large mound which crops out in secs. 26, 35, and 36, T. 113 N., R. 35 W. The usual direction of the joints is N. 35° W. A waterworn condition of the surface is rather marked. Even the highest portions of the mound referred to, from 30 to 50 feet above the river's present level, show potholes and grooves which bear conclusive evidence of water wear rather than of the even cutting of glacial ice. These phenomena of water action are not so conspicuous at this locality as on the summits of the quartzite areas at Courtland, described on page 21, nor so numerous as at several localities farther up the river (pp. 36, 42).

Along the river road from sec. 26, T. 113 N., R. 35 W., westward to Beaver Creek, there are a number of unimportant weathered exposures of the same general character as those above described.

Redwood River area.—Near the mouth of the Redwood River (Pl. VII) the gneisses, showing a typical, distinctly laminated, and uncontorted structure, appear in large areas and cause many tortuous windings in the Minnesota River. The strike is NE.–SW., in places N. 75° E., with a dip sometimes as high as 70° SE. The lamination at this point is conditioned by the parallelism of the constituent minerals. At the northern border of this area of gneissic rocks there is an intercalation of hornblende-schist. It is characterized by a rather coarse texture (sp. 5260), and consists chiefly of quartz granules, triclinic feldspars, and green hornblende, the last occasionally carrying cores of augite. It bears many evidences of descent from the bedded gabbros of the valley. Numerous feldspathic veins form an anastomosing network throughout the whole exposed area of this rock.

REDWOOD RIVER FALLS.

Near the Redwood River, from its mouth to the falls in the city of Redwood Falls, there are many places where the altered gneiss is promnently exposed to view. One spot shows such a complete kaolinization, and at the same time such a staining by ferric oxide, that considerable material has been extracted for the manufacture of brown mineral paint. In sec. 29, T. 113 N., R. 35 W., some quarrying has been done in a gneissic rock which in state of preservation stands about midway between the rock just mentioned as serviceable for a paint and the fine, fresh gneiss at Morton and above Beaver Falls.

The Redwood River has cut a picturesque gorge for itself for a distance of from 1½ to 2 miles from the south wall of the old River Warren to the present Redwood Falls.[1] The walls of this gorge are massive gneissic rocks, reaching 150 feet in height. In all the places cited above almost every stage of decomposition may be seen, from the freshest and finest gneiss down to the impure green kaolin of Birch Cooley, or the "red paint" below Redwood Falls. Usually the quartz constituent of the gneisses is quite fresh and holds its place in lenticular laminæ through the soft material which now makes up the mass of the rock exposures.

Area above Redwood River.—Along the river bottoms above Beaver Falls and Redwood Falls, on both sides of the Minnesota River, there are numerous exposures of biotite-gneisses. In secs. 19 and 20, T. 113 N., R. 35 W., are some large and high rock masses which have to no little degree modified the course of the river, as a glance at Pl. VI will show. In the southeastern corner of sec. 20 are some notable mounds, caused by concentric weathering. Spherical masses of tons' weight lie around. The rocks are, as a rule, of a decidedly fresh aspect; a few are thoroughly disintegrated at the surface, yet have considerable consistency and toughness at the center. They are well laminated. The gneisses exhibit very little variation from the types in the southeastern portion of the Beaver Falls district (Pl. VI). But interlaminated with the hornblende-biotite-gneisses are some interesting hornblende-schists. The schists weather rather more rapidly than the gneissic rocks, and as a consequence they are found in the lower portions of the exposures. They show some variation in texture, in some cases a rather coarse condition being prominent. The structure and mineral composition of the schists are distinctly gabbroid. Hornblende and a plagioclastic feldspar close to labradorite in its optical characters are the chief constituents. The form and structure of these minerals are the same as in ordinary hornblende-gabbros, the only difference being in the complete alteration of the pyroxenic into amphibolic constituents. The strike of the rocks, gneisses and schists alike, where it shows any regularity, is NE.–SW., and the dip is SE. But in places there is great contortion.

[1] Compare Geology of Brown and Redwood counties, by Warren Upham: Geol. Nat. Hist. Survey Minnesota, Vol. I, p. 564.

Origin of kaolinic gneisses.—It may be well to note here the altitude of the kaolinic gneisses, as compared with that of the fresh gneisses, at Morton, Beaver Falls, and several other places along the valley where the fresh rocks and the kaolinic varieties are found. Nowhere does the kaolinic stand at a greater altitude than the undecomposed rock at some place in the immediate neighborhood. At Morton the knobs of fresh gneiss in secs. 30 and 31, T. 113 N., R. 34 W., must reach an elevation at least 100 feet higher than the kaolinic gneiss in the Birch Cooley Gorge. At Beaver Falls dam the fresh, bright hornblende-biotite-gneiss is certainly 75 feet higher than the decayed material beside the road running along Beaver Creek, between the village of Beaver Falls and the Minnesota River bottoms. The same relative altitudes are shown in the gorge of the Redwood River between Redwood Falls and the Minnesota River, and, although to a less degree, near the village of Minnesota Falls and in the city of Granite Falls.

These facts of position tend to show that in the decomposition, which must have been pre-Glacial, the breaking up of the old crystalline rocks could not have been a leveling process, as we understand that term, but that, either through a difference in the hardness of the rock or by reason of other qualifying circumstances, the corrosion reached to great depths in certain places, while in others near by but little effect was produced.

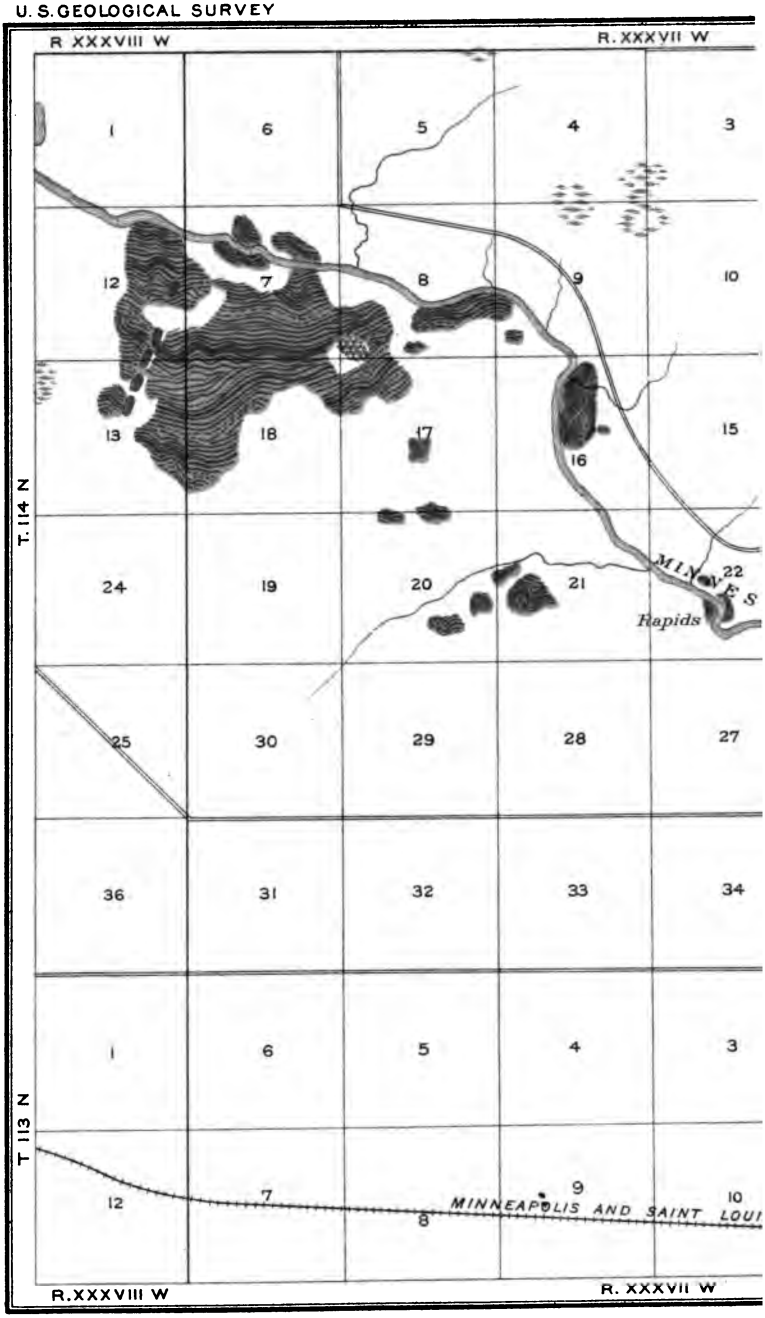
VICKSBURG DISTRICT.

Continuing in a northwesterly direction up the Minnesota Valley (Pls. VIII and IX), there is found, in T. 114 N., R. 36 W., and especially in that portion lying on the north side of the Minnesota River south of the post-office of Vicksburg, an extremely rocky area. The valley here broadens to 4 or 5 miles, with large areas so rock covered that these sections were marked by the land surveyors as "rock barrens." The rocky mounds stand high and bare. Their tops, from 50 to 100 feet above the present river, show many potholes and tortuous grooves from river erosion. As one enters this township from the southwest he finds an extremely interesting series of gneisses and schists. The former are rather acidic in composition, carrying hornblende as the chief basic constituent, and the latter are gabbro-schists of somewhat varying types.

GNEISSES.

Taking the district as a whole, the strike of the gneisses is NE.-SW. Their dip, according to several measurements below Redwood Falls, is SE. at an angle of 70°, while elsewhere the angle was as low as 25°. The general direction of these rocks, both in strike and in dip, is shown on the maps by dotted lines. The gneiss is, as a rule, highly siliceous and strongly banded, 27 laminæ having been counted in a single inch. It is not so contorted as the gneiss around Beaver Falls and

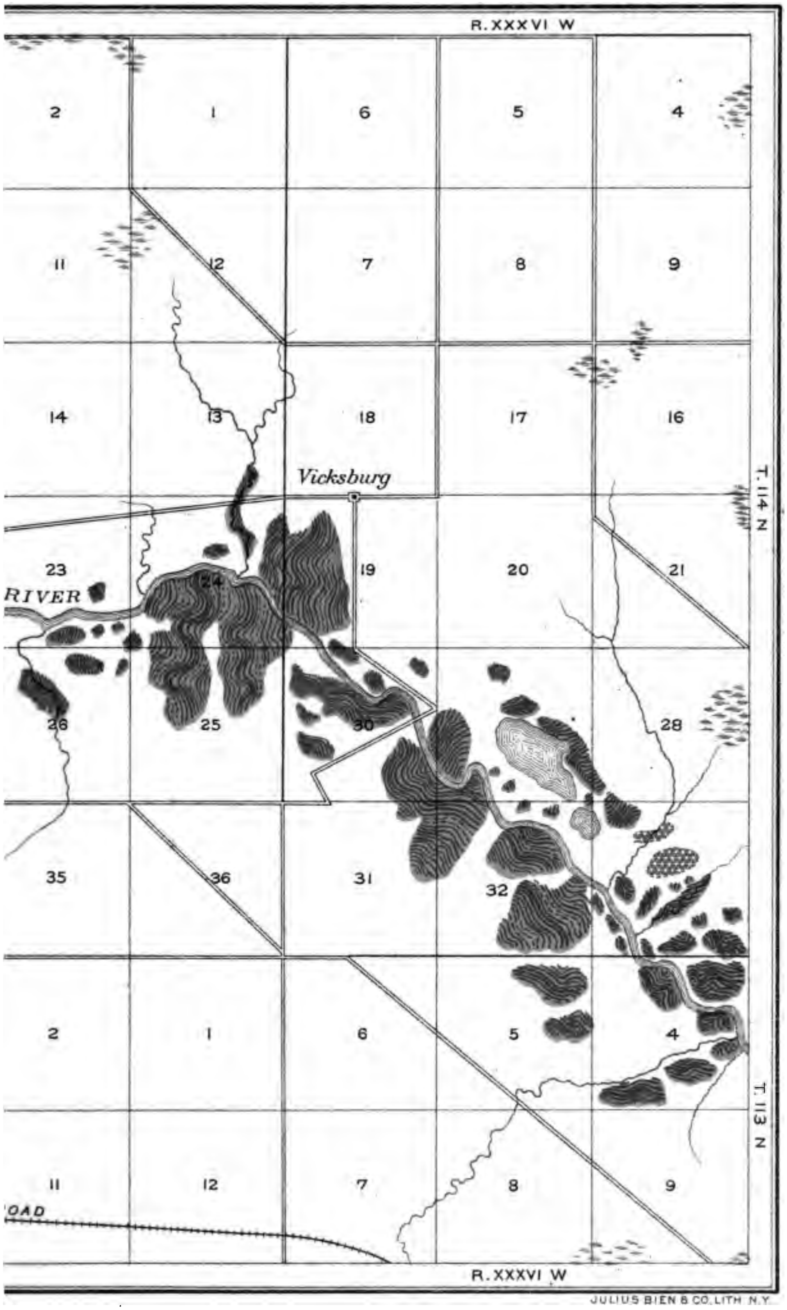
U. S. GEOLOGICAL SURVEY



GEOLOGICAL MAP OF

DIABASE DIKES

GABBRO



VICKSBURG DISTRICT

1 2 MILES

BRO-SCHIST GRANITE AND GNEISS

ROCK EXPOSURES IN THE CENTRAL VALLEY, VICKSBURG DISTRICT.

Morton. In places it is quite epidotic, and almost everywhere it is porphyritic.

In the almost continuous series of exposures in this vicinity the rocks present great diversity of type. In places the gneiss is so massive that no lamination is seen for several feet, while not far away, it may be, a decidedly schistose habit prevails. Large areas are seen with few traces of veins, whether granular or quartzose, while in other and contiguous areas veins are so numerous that scarcely a square inch of surface can be seen which does not carry these segregations. Some rock masses are very fine in texture, while others are coarse and crumbling. Many of the gneisses show an abundance of quartz and potash feldspars, with only a small proportion of the basic minerals, hornblende and biotite; elsewhere hornblende and plagioclases constitute the bulk of the rock, with almost no quartz present. Some stretches of rock surfaces present a prevailingly red color, while others are a decided gray.

In several exposures of the gneisses pyrite and chalcopyrite were seen as accessories. Rarely the latter occurs in sufficient quantity to give a gray or blue color to its associated minerals through the alteration to carbonate of copper.

In one locality, in sec. 8, T. 114 N., R. 37 W., on these same rock barrens, occurs a rock of much interest (sp. 5372, 5373, 5374), which is fully described later (pp. 69–72). It is an augite-biotite-granite-gneiss of not very great extent. The grain is coarse, and the color is a mottled dark green and light green. Streaks of a veinlike mixture of feldspar (microcline) and hornblende appear, with individuals 3 and 4 inches across.

GABBRO-SCHISTS.

In the gabbro-schists associated with the gneisses we have rocks quite different in many of their aspects from either ordinary gneisses or ordinary schists. In texture the schists are medium to fine, and in structure they are distinctly laminated. The strike of the lamination is NE.–SW., and the dip is 25° SE. The rocks are laminated gabbros, and so far as general characters are concerned they appear much like the flaser-gabbros of the German lithologists, particularly those described by Lehmann.[1] These gabbroid rocks must be very ancient, since they are broken through by the diabase dikes so common in the valley, and are apparently interbedded with the gneisses with which they are associated. They will be described further in Chapter V.

In this vicinity, in sec. 33, a white variety of hornblende—tremolite—was seen in one rock, an occurrence somewhat rare in the valley. Near it occurs a garnetiferous hornblende rock which carries diallage, the mineral from which, by its alteration, a portion of the white hornblende springs.

[1] Enstehung d. altkryst. Gesteine, 1884, p. 194.

GRANITE FALLS DISTRICT.

Directly on the line between T. 115 N., R. 38 W., and T. 115 N., R. 39 W., in sec. 19 of the former and in sec. 24 of the latter (Pl. X), gabbro-schist occurs. The rock stands in nearly vertical position. It is so shattered that measurements of strike and dip are somewhat uncertain. The strike was determined as N. 65° E., the dip being SE. at an angle ranging from 75° to vertical. The texture is very fine, and geodized masses of quartz occur. Only one other place is known in the valley where a schist as finely textured as this occurs in place. That is in sec. 17, township of Omro, 115 N., R. 43 W. This peculiar rock is not infrequent in the form of drift bowlders in various parts of Minnesota. Large masses have been found at Litchfield, T. 119 N., R. 31 W., at Minneapolis, and at many other places. These occurrences point to a somewhat wide distribution of this hornblende-schist beneath the drift.

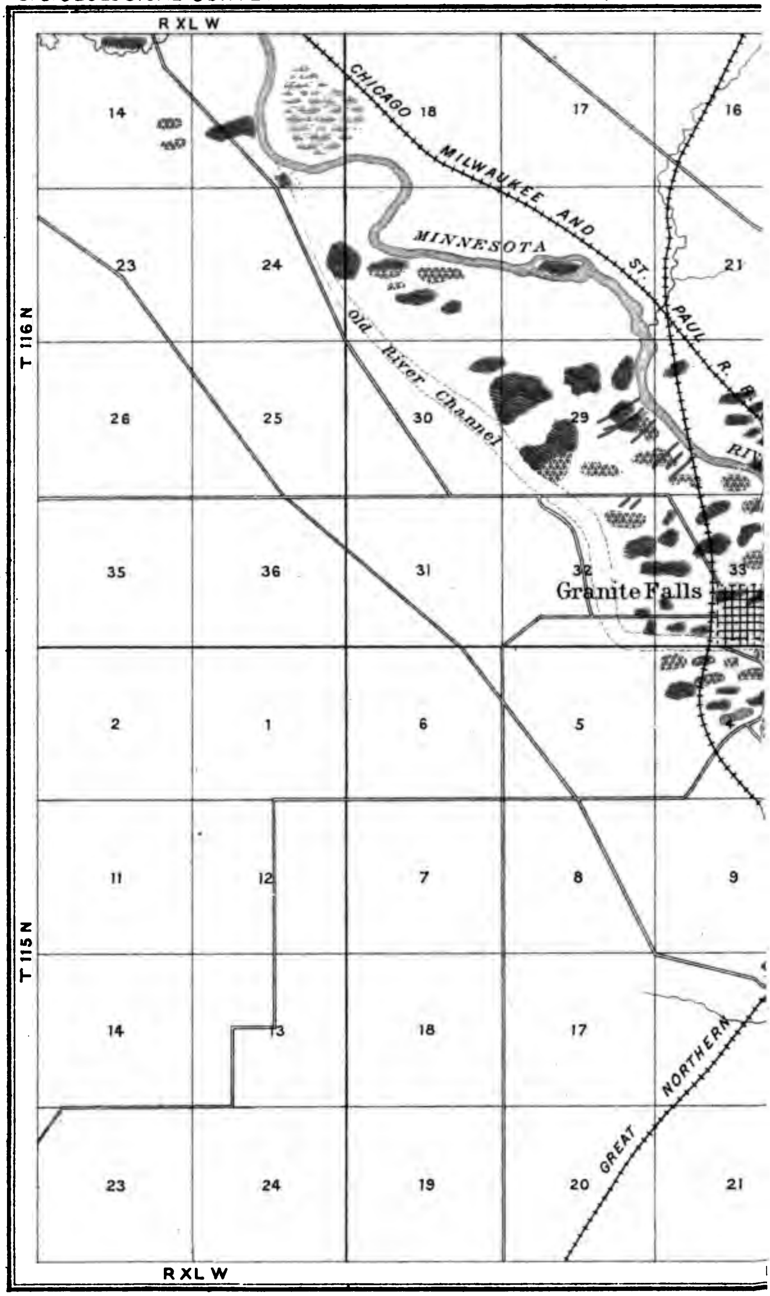
A mile and a half northwest of these gabbro-schists of secs. 19 and 24 begins an interesting series of gneisses, diorites, and pyroxenic schists of a markedly gabbroid character. Through Minnesota Falls and Granite Falls a succession of folds can be traced in which this series of interbedded gneisses and schists dips alternately S. and N. at angles usually less than 35°. To the south of Minnesota Falls the dip is southerly, changing to northerly in Minnesota Falls itself. In Granite Falls the dip again changes to a southerly direction, and this in turn gives place to a northerly dip, as the long series of billowy masses of crystalline rocks finally disappears under the masses of glacial drift and river silt which conceal all the rock exposures between the northern part of Granite Falls and Montevideo.

The gneissic rocks take the leading place in point of area underlain. In texture and composition they exhibit some modifications which are of interest. They are nowhere granitoid. The lamination is clear and distinct, with a strike varying little for many miles, being ENE.-WSW. The color is gray or reddish gray, and the texture medium grained. The proportion of quartz among the mineral constituents is very high. The feldspathic constituent is largely plagioclastic, of the soda-lime variety, and in places is somewhat kaolinized, thus giving a bleached appearance to the mineral. The kaolinization seems to pervade orthoclase and plagioclase alike. The basic minerals are both hornblende and biotite, the former predominating.

On the north side of the river, in sec. 28, T. 116 N., R. 40 W., a great many small garnets appear within the gneissic rocks. These show all stages of alteration into biotite; and biotite remote from the garnet patches is comparatively rare.

Inclusions and bands of hornblende-augite-schist are rather frequent in the gneisses.

As shown by microscopical examination (see pp. 85-93) the dark-colored rocks of this locality are schistose gabbros. So far as can be seen these schistose gabbros conform in position with the gneisses and



GEOLOGICAL MAP OF GRA

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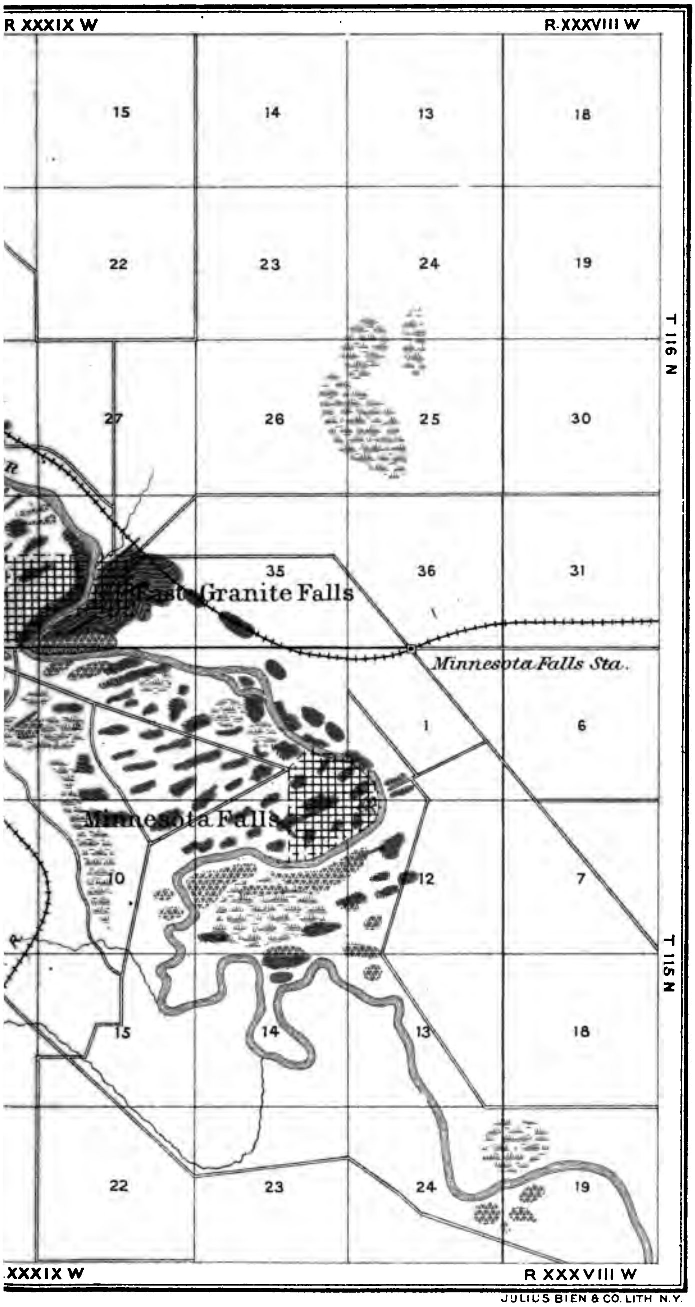


ITE FALLS DISTRICT

1 2 MILES

O AND GABBRO-SCHIST
ING GABBRO-DIORITE

GRANITE AND GNEISS

diorite-schists. They carry numerous garnets. At the surface the augite is, to a considerable extent, altered to biotite. It is probable that the garnets also, by their decomposition, have added materially to the amount of biotite present in the rocks. In the deeper beds the schists have a fresher look. They carry little biotite, but are rich in hornblende. A heavy stain of ferric oxide is everywhere present on the weathered surfaces, both of the surficial rock and along internal fractures exposed in quarries and railway and highway cuts.

Evidences of water erosion, potholes, tortuous grooves, etc., are found at a considerable height above the present river.

This district can not be passed without mentioning the bed of gabbro-schist, described in detail on pages 87 and 88, which occurs in sec. 32, T. 115 N., R. 40 W., 1,750 paces N., 250 paces W. It covers an area of small extent, the exposed surface being only 25 paces long and 20 paces wide. Over its whole surface this rock is profusely veined. While its contact with the surrounding rocks can not be seen, it is no doubt conformable with the beautifully contorted gneiss which stands out to view only 40 paces to the north. The gabbro-schists throughout the district present as pronounced a lamination as do the gneisses themselves. In color they vary from dark green to black, and they fade out very perceptibly on weathering. These rocks are further described on pages 85–93.

All the rocks, gneisses and gabbro-schists, are cut through by the dikes. The number of dikes crossing the valley through this district is large. There is great diversity in their width as well as in their massiveness and texture. They have one general direction, from the northeast to the southwest, but locally the direction varies to some extent. All these dikes are diabasic, or were originally, although many of them are now much altered. The change is more marked in the southern portion of the area. This difference may be due to a long time interval between the intrusion of the dikes of the southern and northern areas.

Veins are frequently seen in all the different rocks of this district. The coarse granitic material of several of the veins is noticeable, while the milky quartz veins, which are not infrequent, have been found to carry traces of gold. Much quartz, in lenticular masses or segregations, is to be seen in these rocks, as well as in the deposited masses in the areas bordering the fissures.

While there is no evidence at hand to show that the rocks of this district are eruptive, all indications, if any ever existed, of a sedimentary origin for any of them, whether basic gabbro schists, semi-basic diorites, or acidic gneisses, have been obliterated in the subsequent transformations through which they have passed. The characters of every class of rock in the area are such that most geologists would regard them as evidence of eruptive origin. All evidences of any different condition at any previous geologic period point to the alteration

of some other crystalline rock rather than to the upbuilding from an originally clastic mass into the present perfectly crystalline condition. Still, no undoubted evidence of eruptive origin exists here. Lawson has pointed this out[1] in the case of similar rocks in his upper division of the Archean rocks of Ontario.

The area about Minnesota Falls has been, at least twice within its geologic history, the scene of profound volcanic disturbances. At the first, great quantities of rock were intruded. At least a portion of these rocks was basic. During the profound foldings which the Archean crust has undergone throughout the entire Northwest, these rocks were made schistose and were infolded with the associated acidic and gneissic rocks. It was after such folding that another period of volcanic activity ensued, and dike after dike of basic material appeared. Whether an overflow of extensive beds of this dike material occurred can not be determined, but the probabilities are negative; nor will it be known whether all these dikes were formed at the same epoch. Observations have not shown any two dikes crossing each other, and this bears strongly against successive epochs of intrusion. Many things point to the probable Keweenawan age of these outbreaks. Whether the Minnesota River Valley dikes be or be not of Keweenawan age, this much at least can be said, the Cambrian rocks of the Northwestern States have not, up to this time, disclosed a single dike of volcanic material. On the other hand, in many places rocks unquestionably of igneous origin have been discovered beneath the horizontal sandstones, shales, and dolomites affirmed by all paleontologists to be of Cambrian age.

MONTEVIDEO DISTRICT.

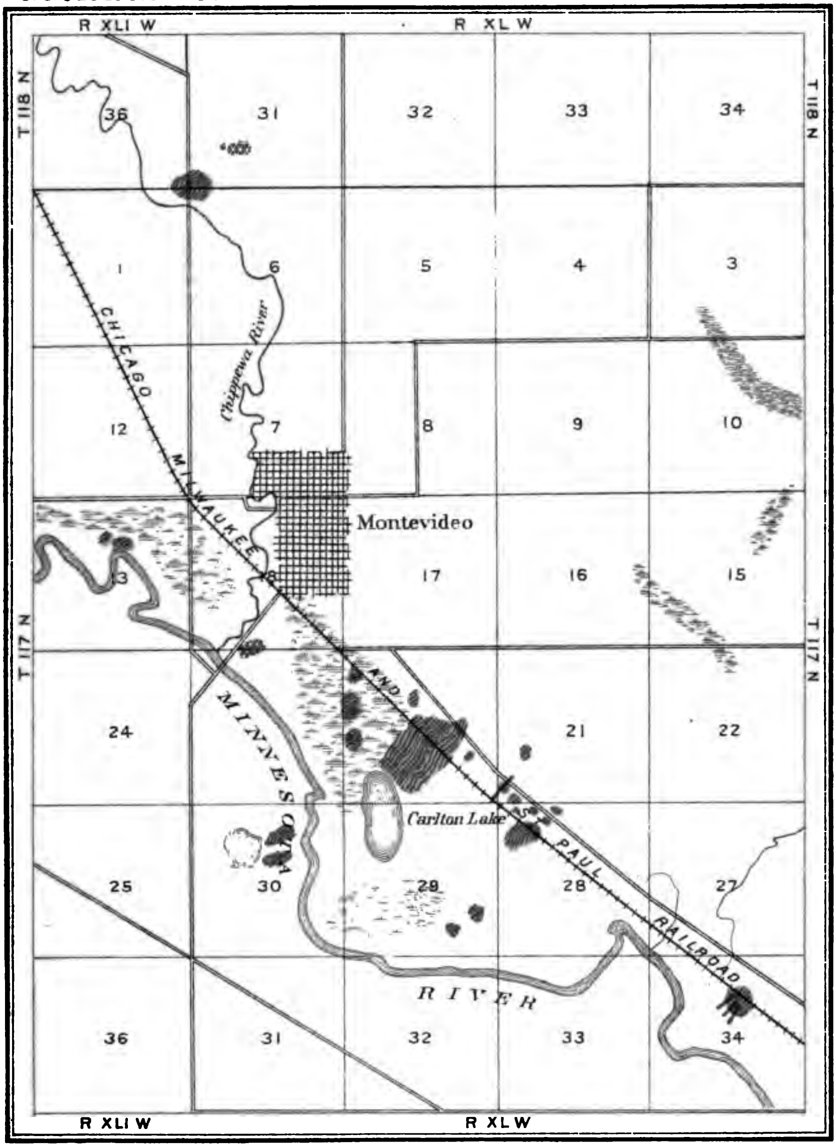
In the western part of Chippewa County there is an area of biotite gneissic rocks of sufficient interest to receive attention. (See Pl. XI.)

At Montevideo the gneiss, which is strongly banded, has a red color. The strike in the vicinity is very nearly NE.-SW., with a uniform dip varying from 30° to 50° SE. The surfaces of the rocks are much waterworn, more even than at Granite Falls. Potholes and irregular grooves are numerous.[2] One of the potholes is at least 8 feet deep and 3 feet in diameter. Deposits of modified drift surround these worn surfaces. In many places, as at Montevideo, these evidences of water erosion are at a considerable height above the present river, being at least 50 feet at a railway cut near Montevideo, and not less than three-fourths of a mile distant from its channel.

The peculiar kaolinized gneiss, which occurs in many places farther down the river, seems here to have entirely disappeared, the last exposures of such kaolinized gneiss occurring at Granite Falls, at the

[1] The internal relations and taxonomy of the Archean of central Canada, by A. C. Lawson: Bull. Geol. Soc. America, Vol. I, 1890, p. 178.

[2] Geology of Swift and Chippewa counties, by Warren Upham: Geol. Nat. Hist. Survey Minnesota, Vol. II, 1888, p. 212.



GEOLOGICAL MAP OF THE MONTEVIDEO DISTRICT

Scale

1 0 1 2 MILES

DIABASE DIKES GABBRO AND GABBRO-SCHIST GRANITE AND GNEISS

JULIUS BIEN & CO. LITH N.Y.

corner of Prentice and Thursey streets, and in a gorge opposite Minnesota Falls, on the north side of the Minnesota River, in the west half of sec. 2, T. 115 N., R. 39 W.

Dikes occur having a NE.-SW. direction, as in the Granite Falls district, which show some interesting phases of composition. Taken as a whole they are not so much altered as at Granite Falls. Some of them are heavily loaded with quartz. Their coarseness varies with their width.

At two or three localities in this district the gabbro-schist rocks appear. One locality is near the line between secs. 18 and 19, T. 117 N., R. 40 W., where the rocks stand in rounded knobs 30 feet or more above the river. There seems to be in this exposure an abnormally large amount of quartz. The presence of this mineral, bearing every evidence of infiltration, is probably the cause of the resistance to erosion shown by these knobs, for the rocks around them have been eroded to a depth which must be considerably below the surface of the

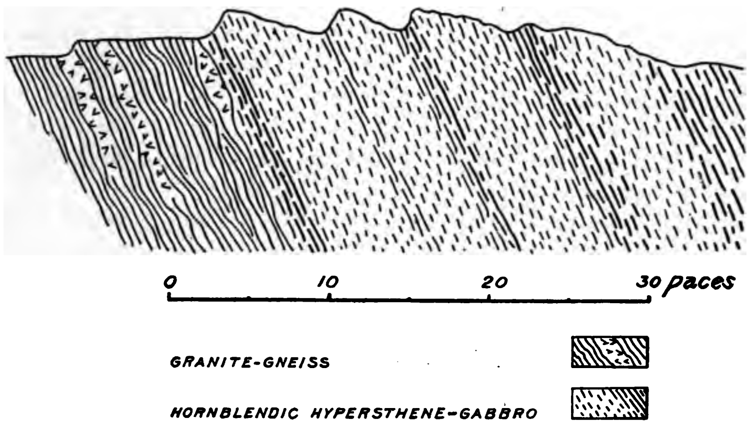


FIG. 6.—Contact of granite-gneiss and hornblendic hypersthene-gabbro-schist near Montevideo.

present alluvial beds of the river valley. Another interesting exposure of this type of rock was seen in sec. 31, T. 118 N., R. 40 W., 2½ miles due north from Montevideo.

The area is small, only 60 paces long and 30 paces wide. The rock is dark gray, somewhat imperfectly laminated, and of medium texture. The strike of the laminæ is N. 30° E., and their dip 55° SE.. The laminæ are bent sufficiently to give a wavy appearance, but not enough to make a contorted schist. Indeed, nowhere in the valley have these gabbro-schists exhibited a degree of irregularity in direction of lamination that would entitle them to be called contorted. (See fig. 6.) While the gneisses are contorted in many places, this condition has never been noted where the gabbroids occur in proximity. In mineral composition this rock is a hornblende-hypersthene-gabbro. It is fully described in Chapter V.

LAC QUI PARLE DISTRICT.

For several miles above Montevideo there are few rocks in sight. The bluffs on either side of the Minnesota River slope off in smooth and rounded outlines from the prairie level to the bottoms, a descent of about 100 feet. Lac qui Parle, the "Echo Lake" of the Indians, is simply a broadening of the Minnesota River for several miles of its course, as the result of a dam of silt deposited across the valley by the Lac qui Parle River, which empties into the Minnesota some little distance below the foot of Lac qui Parle. (See Pl. XII.)

The sloping and rounded bluffs on opposite sides of the river are from 1 to 3 miles apart. With the long lake and the meadows between, these bluffs outline a landscape of rare beauty. Along the north side of the lake there is a large tract which is in much of its extent rather swamplike and in times of flood is covered with water. A great portion of it, however, makes highly productive farms. The rocks throughout the valley are mostly covered. The few exposures show a gneiss with distinct lamination, having a strike N. 70° E., with a dip as high as 80° SE. Most of the rock is a hornblende-biotite-gneiss. It is microscopically described in Chapter IV. There are both finely textured and coarsely textured gneisses in this district. The exposures at the lower end of the lake and along its south side seem to be much the finer and lighter colored.

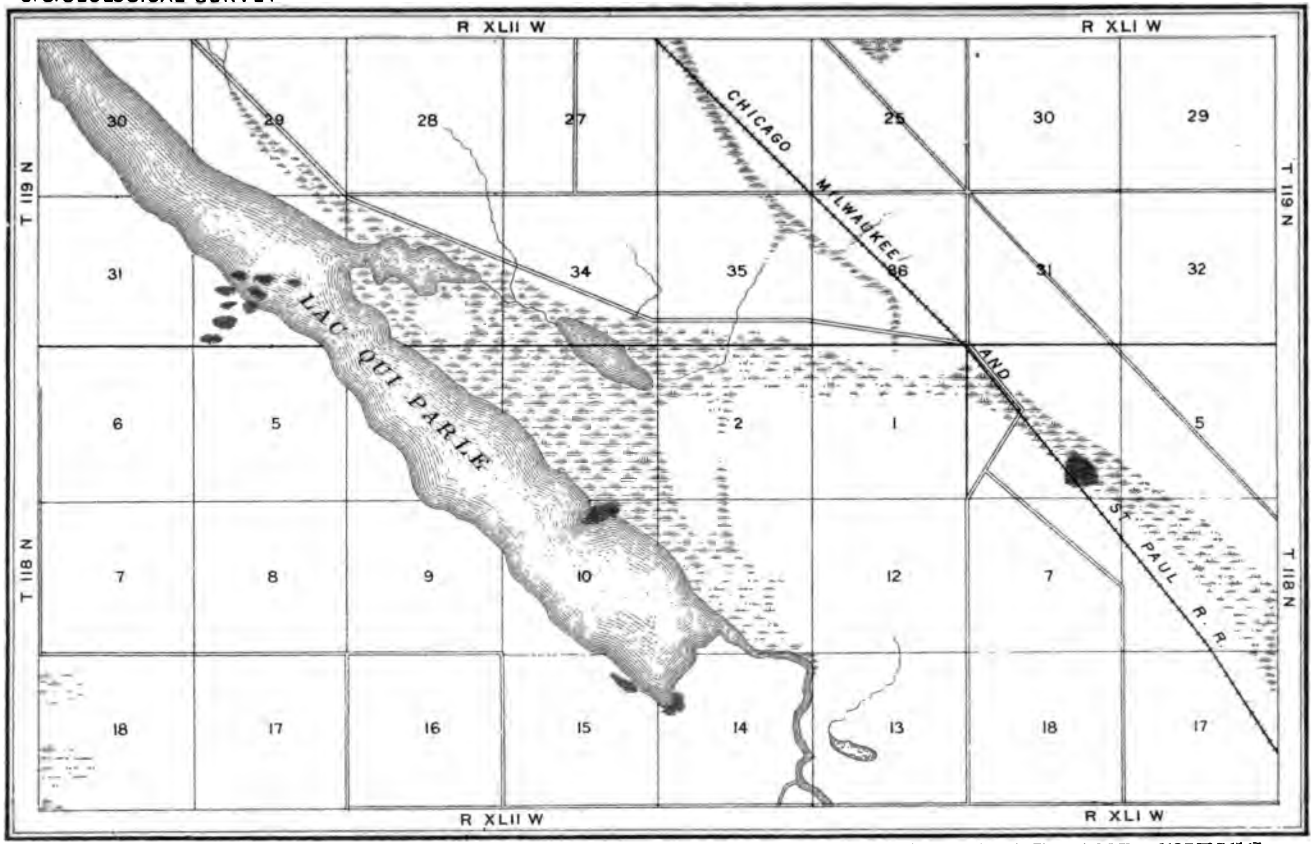
Everywhere the rocks carry an unusual number of veins. These veins are sometimes several feet across, and again almost of paper thinness. In places they are quartz, and elsewhere they are granitic in composition. The quartz veins are seldom of great width, and as a rule are lenticular within the laminæ of the inclosing gneiss.

ORTONVILLE DISTRICT.

Passing from Lac qui Parle toward the Odessa district, on the north side of the valley, one finds no exposures between those in sec. 32, T. 119 N., R. 42 W., and those in sec. 20, T. 120 N., R. 44 W. In the Marsh Lake area large masses of gneissic rocks appear on both sides of the river. Their position seems to mark an ancient channel of the glacial River Warren. The large rounded knobs show beautifully glaciated surfaces, with striæ nearly parallel with the course of the valley.

In the center of this district (Pl. XIII), along a line extending from sec. 31, T. 121 N., R. 44 W., in a SW. direction through secs. 9 and 15, T. 120 N., R. 45 W., there seems to be an axis of a subordinate anticline; at least to the east of this line the dip of the schistosity is southeasterly, while to the west for several miles there is a northwesterly dip. Within the townships just named there is considerable diversity in the character of the rocks. The larger portion is a hornblende-biotite-gneiss with interlaminated bands of biotitic schist.

In sec. 9, T. 120 N., R. 45 W., there stand two or three knobs of a bio-



GEOLOGICAL MAP OF LAC QUI PARLE DISTRICT, SHOWING GRANITE AND GNEISS

Scale

1 0 1 2 MILES

titic quartz-pyroxene-schist. So far as mineral constituents are concerned, this rock is very similar to the gabbroid schists from the several localities in the valley already mentioned.

We have here, as well as in the districts already described, rocks which for convenience have been termed "squeezed eruptives" by the lithologists who have studied them for other regions. Large areas of rocks, possibly spread out as flows of igneous matter, together with rocks of different chemical and mineral composition, were squeezed in the continental movements subsequent to their extrusion to such an extent that a schistose structure was induced. Subsequent conditions have no doubt played their part in bringing these rocks to their present mineralogical and structural states.[1] The fine crumpling so often seen in this structure is absent in the schistose rocks of the Minnesota River Valley.

In the old gorge of the River Warren, in secs. 9, 15, and 16, T. 120 N., R. 45 W., around the mouth of the Yellowbank, a small creek

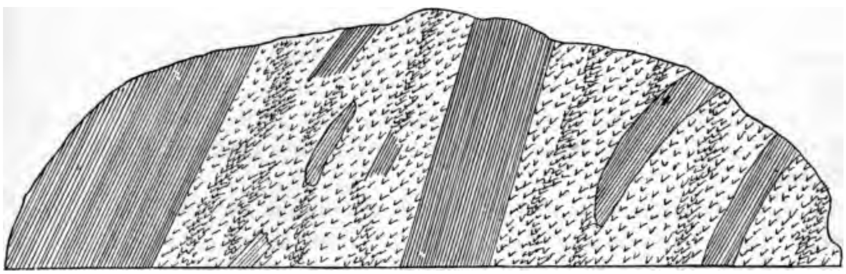


FIG. 7.—Exposure of granite-gneiss and hornblende-biotite-schist, showing alternation of the two rock species, sec. 15, 1,200 paces N., 1,600 paces W., T. 120 N., R. 45 W., Minnesota.

which enters the Minnesota River near this place, are some interesting alternations of gneiss and biotite-schist, though so small a part of the rocks of this locality is in sight that only occasional glimpses of them could be gained. The two types of rock are interlaminated, sometimes in belts several feet in width and sometimes in bands less than an inch wide; while lenticular inclusions of the schists in the gneiss are frequently to be seen. Fig. 7 shows this relation. Here and there a pegmatitic condition of the more feldspathic gneissic portions stands out in sharp contrast with the bordering schistose belts.

The gneissic condition is evidenced, not in the ordinary lamination presented by alternating biotitic and feldspathic bands, which as a rule characterize the gneisses of this valley, but in the prevailing direction of the large and porphyritic feldspar crystals.

Around Odessa are several gneissic exposures of interest. To the east, where the Chicago, Milwaukee and St. Paul Railway comes down from the prairie around Appleton and Correll to the river bottoms, which it follows from Odessa to Ortonville and Bigstone, the gneisses outcrop in fresh, firm masses.

[1] Geology, Chemical, Physical, and Stratigraphical, by Joseph Prestwich, Vol. I, 1886, p. 270.

In sec. 31, T. 121 N., R. 44 W., 700 paces N., 1,350 paces W., within a few paces of milepost 168 of the railroad, a porphyritic granite and gneiss appear, with inclusions of schist. The main mass of the exposure is gneiss; in places it is granitic. The feldspar crystals are frequently 1½ inches in length. Their color is a light pink, and they abound in inclusions of quartz and even of other feldspars. Sulphide of iron is so abundant that almost every fresh fracture discloses it. The species is presumed to be marcasite, since it readily decomposes on exposure to the air and covers the rock surfaces with an iron rust. The schist inclusions exhibit a fine-grained dark-colored hornblende-biotite rock with secondary fine-grained quartz and several feldspars.

Only 300 paces from milepost 169, in sec. 36, T. 121 N., R. 45 W., is another set of exposures showing similar types of rock. A distinct gneissic structure prevails, the lamination running N. 20° E., with a SE. dip. Schistose inclusions abound. In this respect these exposures are essentially the same as the large bowlder mentioned by Upham, and referred to on the next page.

In the low, swampy area along the river, south of the knobs just located, are many outcrops of gneissic rock almost identical with those near the railroad, just noted. In places a sharp lamination is seen, and again the rock becomes so granitic that it is only in the parallel position of the feldspar individuals that any gneissic structure is disclosed.

A short distance west of the station at Odessa several small knobs occur, different in no essential particular from the gneiss and granite near mileposts 168 and 169, above mentioned. The word "granitoid" well describes the texture. The strike of the masses is nearly N.-S., and the dip is 40°-45° E. The rock as a whole is not in so good a state of preservation as that nearer the river—a fact very commonly noted in rocks lying along river courses.

Within the 3 miles of the valley immediately below Ortonville there are many large areas of a granitoid gneiss. The rocks generally dip toward the northwest at a high angle. This gneiss has a prevailing red color (see Pl. XVI, *A*), varying at times to gray through the increase in the quantity of biotite and hornblende. The feldspar crystals are frequently large. Below the railway station at Odessa are two or three glacial moraines which carry an enormous amount of granitic and schistose material. Bowlders of these rock types constitute a large portion of the material in many places. The proportion of the crystalline rocks in this glacial débris is evidence of enormous glacial erosion of the Archean rocks lying in the region stretching northward and northeastward from the Minnesota River. Warren Upham mentions this accumulation of bowlders,[1] and explains it as a morainic plain whose material, accumulated in an early epoch of the great Ice age, was partly buried beneath the débris of subsequent southeast-

[1] Geology of Bigstone and Lac qui Parle counties, by Warren Upham: Geol. Nat. Hist. Survey Minnesota, Vol. I, 1884, p. 626.

ward extensions of the ice. The surface of this plain stands 50 to 75 feet above the river and 50 feet below the top of the bluffs, or the general prairie level. The bowlders composing this débris are quite large in places. Upham mentions one 30 feet or more in diameter, and another, of gray granite, measuring 20 feet, "in which are seen at one side several fragments of hornblende-schist up to 3 and 4 feet in diameter."[1] The writer and his assistant, Mr. J. E. Manchester, took a midday lunch in the shade of a bowlder of granitoid gneiss lying near the bluff on the south side of sec. 11, T. 120 N., R. 45 W., which measured 15 feet in height, 34 feet in width, and 43 feet in length. Its weight was estimated to be over 100 tons.

In this mass of glacial drift there is much fine material, apparently to some extent calcareous, intermingled with occasional calcareous bowlders. Most of this calcareous material has, no doubt, been torn from the Minnesota shales and limestones of Cretaceous age.

The surfaces of the granitoid gneisses immediately below Ortonville are well worn and rounded by glacial erosion. Indeed, no better exhibition of the roches moutonnées of glaciated districts can be seen in the whole valley. Any unevenness in the hardness of the rock is clearly indicated by the grooves and protuberances on the surface. The direction which the ice took down the Minnesota River Valley was almost the course of the present stream. There is no doubt that the River Warren occupied the same course. The grooves and striæ which indicate this direction can be distinctly seen on the surface of almost every rock within the first 3 miles below Ortonville, and also in the old river channel now in part occupied by the unruly and tortuous stream, Yellowbank Creek, which empties into the Minnesota River on the south side of sec. 34, T. 121 N., R. 45 W.

To the southwest of Ortonville, in sec. 16, T. 121 N., R. 46 W., stands a considerable mass of granitic gneiss, which is the most westerly exposure of this rock now known in this valley. Indeed, this is the last granitic outcrop in the whole Northwest until the great uplift of the Black Hills of South Dakota is reached. Deep wells bored in several South Dakota towns to the west and southwest show these rocks at from 50 to 100 feet below the surface. Millbank, 10 miles west of the Minnesota State line, has bored several wells with that result.

REDWOOD RIVER VALLEY DISTRICT.

Having passed in brief review the most notable rock exposures of the valley as they lie bounded on either side by the sharp ridges of morainic material, we will now note the few outcrops of crystalline rocks known to stand upon the prairies to the south and west of the Minnesota River and north of the quartzites which are probably continuous from Courtland to Pipestone. The gorge of the Redwood River from the south border of the Minnesota River bottoms into the

[1] Geology of Bigstone and Lac qui Parle counties, by Warren Upham: Geol. Nat. Hist. Survey Minnesota, Vol. I, 1884, p. 626.

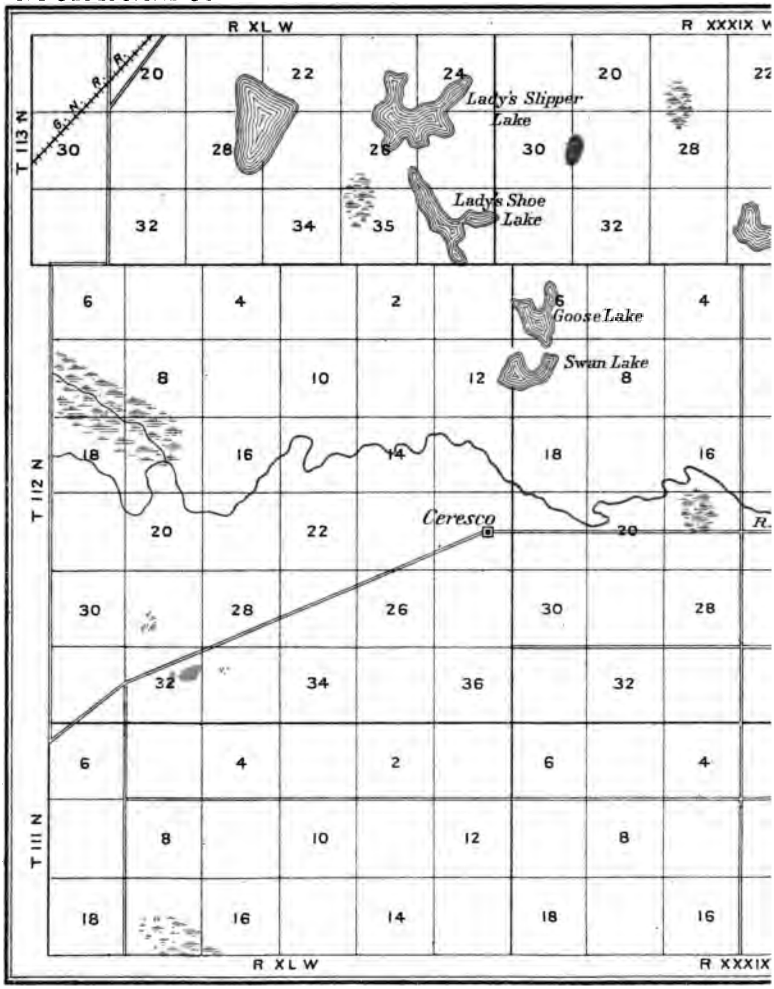
middle of the city of Redwood Falls is one of great natural beauty and interest. The rock is a gneiss, so altered in places that it has become an impure kaolin, sometimes green and sometimes red. From that completely changed condition to one of a fresh and tolerably firm building stone there is a well-graded series. Cretaceous beds overlie these gneisses in places. The length of the gorge must be at least 2 miles, although the air-line distance is considerably less. At the head of this gorge is a cascade 25 or more feet in height. (See Pl. VII.) The rock here is much fresher than at points farther down the stream. Above this principal cascade are several rapids where the water tumbles over floors of gneiss. Beyond, a few hundred paces, no rocks appear, save occasional bowlders, until miles of the slowly ascending prairie have been traversed.

Beyond the falls of the Redwood River in the city of Redwood Falls one loses sight of all rocks, the bed of the Redwood River resting upon the glacial till of the prairies. Artesian and deep wells sunk in Redwood Falls and several places on the prairie to the west, whenever deep enough, pass entirely through the glacial drift and all other fragmental deposits and disclose the gneissic rocks, which lie at depths varying from a few feet to 300 or 400 feet. So it may be positively maintained that gneissic rocks underlie the whole district. In three or four townships south of the river small areas of gneiss are seen at the surface (Pl. XV). These are all areas of a distinctly laminated, very quartzose, hornblendic, and biotitic gneiss, in places considerably contorted. Their surfaces are unusually well preserved. They must stand from 1,050 to 1,200 feet above the sea, and thus between 200 and 350 feet above Bigstone Lake, which is practically the head of the valley. Where the covering of glacial débris has been but recently removed, beautifully polished surfaces are disclosed. In sec. 32, T. 113 N., R. 38 W., the glacial striæ show a direction S. 65° E.

POST-CAMBRIAN DEPOSITS.

In the Morton and Beaver Falls districts (Pls. V and VI) there are several exposures of supposed Cretaceous sandstones and shales. Along the Minneapolis and St. Louis Railroad, from the prairie town of Franklin down to the river bottoms at Morton, several cuts have been made in a medium-grained white sandstone. Beside the wagon road between the Franklin station and the bottoms in sec. 10, T. 113 N., R. 35 W., in the bluffs, where the glacial débris has been removed in the construction of the highway, there are exposures of a white sandstone. Again, in the gorge of Birch Cooley Creek, on the line between secs. 32 and 33, and also just above the old mill in sec. 28, all in T. 113 N., R. 34 W., are exposures of horizontal, well-bedded white sandstone of medium grain and slight induration. These exposures are undoubtedly a continuation of the same beds that are seen along the railroad *at the same* and somewhat lower altitudes. The exact thickness of

U. S. GEOLOGICAL SURVEY



GEOLOGICAL MAP OF THE REDWOOD RIVER D

Scale

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GRANITE

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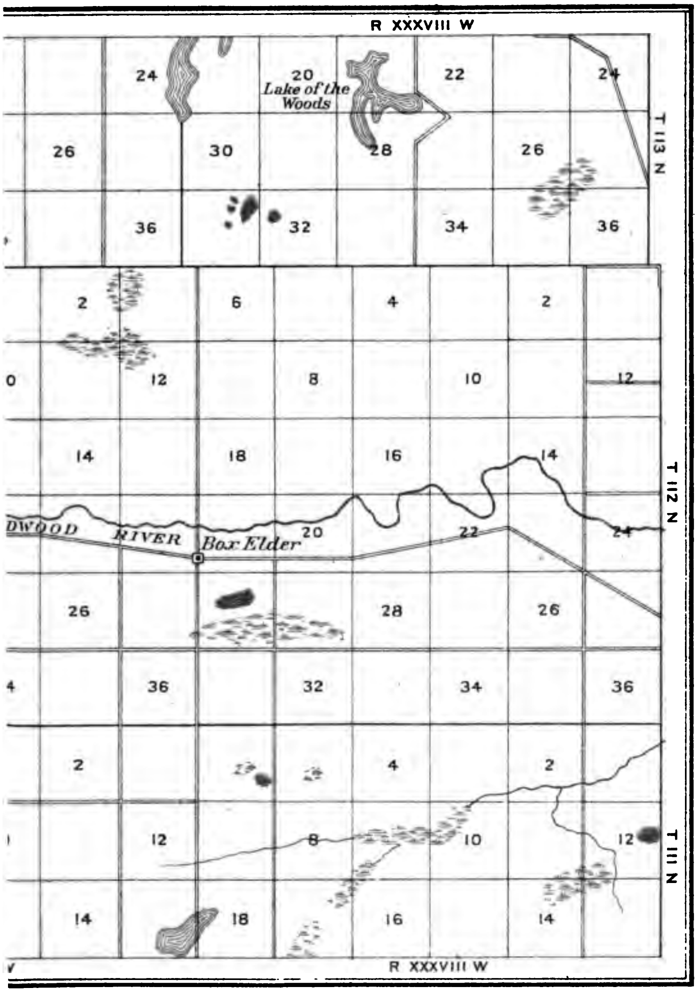
BULLETIN No. 157 PL. XV.



STRICT, SHOWING GRANITE AND GNEISS

3 4 5 MILES

ND GNEISS

CO. LITH N Y.

this sandstone can not be stated, but nowhere is an exposure more than 12 or 15 feet thick.

In sec. 5, or vicinity, T. 112 N., R. 34 W., there is reported "an exposure of sandy marl, horizontally stratified, seen in the road that descends from the Lower Sioux Agency to the ferry [across the Minnesota River]."[1] Along Crow Creek shales appear, and along the Redwood River both shales and seams of lignite occur.[2] These Cretaceous rocks are not well compacted. The exposures stand at some little height above the river, and appear to rest in protected spots where the higher gneissic bluff protected them from glacial erosion. This rock was first observed by Keating,[3] who mentions a fine white sandstone as forming the bluffs at a place corresponding to this portion of the valley. "In the sandstone exposures I saw no fossils, nor were other facts observed which could bear on geological age." Geographical situation and lithological characters naturally assign them a place with the beds along the Cottonwood River, already mentioned in the discussion of the New Ulm area in the Cretaceous.[4]

The lignites have at various times excited considerable local interest, but all efforts at profitable working have been thus far in vain.[5] No systematic exploration has yet been done to determine the economic value of the deposits or to work out the fauna or flora.

Between the quartzite exposure near Redstone and the "basal conglomerate" of sec. 27, T. 110 N., R. 30 W., and near the line between secs. 27 and 32, there is a bed, apparently thin, of poorly compacted limestone intermingled with shales and sand. On the south side of the Minnesota River, in a terrace stretching to the southeast nearly parallel with the river, is another deposit of the same lithological character. No doubt the two deposits are portions of the same bed, which has been cut in two by the Minnesota River. The present existence of this limestone is doubtless due to the protection afforded by the quartzite bluffs to the north and east, which stand considerably higher than any limestone exposures observed. The rock is used for making lime at several kilns. As taken from the quarries its appearance is peculiar. It occurs in corroded and vesicular blocks and in crystalline masses. The color of these masses on freshly fractured surfaces is seldom uniform, but varies from white to brown. It does not appear to be an extensive formation, either in thickness or in area.

Along the Big Cottonwood River, to the west of the exposures named, and probably separated from them by river and glacial erosion, are beds of sandstone. They are horizontal, fairly well bedded, unevenly

[1] Geol. Nat. Hist. Survey Minnesota, Vol. I, 1884, p. 577.

[2] Compare The geology of the Minnesota Valley, by N. H. Winchell; Geol. Nat. Hist. Survey Minnesota, 1873, pp. 187, 188; also Warren Upham, Final Rept., Vol. I, 1883, p. 572, et seq.

[3] Narrative of an Expedition to the Sources of the St. Peter's River, Lake Winnepeek, Lake of the Woods, etc., by William H. Keating, London, Vol. I, 1825, p. 362.

[4] Ante p. 21.

[5] Geology of Brown and Redwood counties, by Warren Upham; Geol. Nat. Hist. Survey Minnesota, Vol. I, 1884, p. 577.

textured, and generally white in color, although some of the layers are brown, particularly in the center of the exposed beds of the river gorge in sec. 36, T. 110 N., R. 31 W. At this location, in the lenticular layers of sandstone on the north side of the river, where a shady condition is favorable for their preservation, many fossil leaves have been found. These are *Populites elegans* Lesq., *P. litigiosus* Lesq., *Ficus austiniana* Lesq., *Magnolia alternans* Heer, *Protophyllum credneroides* Lesq., *P. intergerrimum* Lesq., and *Laurus plutonia* Heer, indicating that the rocks are of the Dakota formation of the Cretaceous.[1]

In general the data regarding the stratigraphy of western Minnesota, accumulated through the records of deep wells, go to show that a large portion of this district has a series of Cretaceous beds sandwiched between the drift deposits and the Paleozoic and pre-Paleozoic formations, which extend under ground westward from the central and eastern portions of the State. These Cretaceous beds are not at present of great thickness, nor are they of uniform composition and succession, as is shown by a comparison of borings from different localities. This area, being doubtless on the eastern border of the great Cretaceous gulf, could never have received the enormous sedimentation which accumulated through the western portion of the Dakotas and southward. The present thickness of the Cretaceous and of the drift accumulations together represents at most only a few hundred feet of sediments. Owing to their soft character, these partially compacted deposits easily yielded to the abrasive action of Glacial time. It can easily be noted by the geologist crossing Minnesota from east to west that the character of the drift débris gradually undergoes a change. In the east it is predominantly siliceous. The pebbles are chiefly from the great terranes of the pre-Cambrian series, and where calcareous pebbles occur they seem to be wrought out of the Cambrian and overlying formations of the Paleozoic, their fossils proving their age.[2] Water in the streams is somewhat hard, yet not objectionably so. In the west a fine calcareous shale, seldom appearing in large bowlders, gives a different texture to both the till and the modified drift. The color of the morainic material is different. Water from its springs is hard and far from pleasant for domestic use. Near Ortonville are springs which yield sufficient quantities of the carbonates of calcium and magnesium to deposit considerable masses of travertine. Travertine deposits are not infrequent in the upper portion of the valley. Magnesium salts and other compounds are usually seen in dry weather as efflorescences covering low grounds and desiccated sloughs throughout western Minnesota.

North of the Ortonville district Paleozoic limestones and fossils constitute a considerable portion of the drift material. At Morris and

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[1] Geology of Brown and Redwood counties, by Warren Upham; Geol. Nat. Hist. Survey Minnesota, Vol. I, 1884, p. 573. See, also, Cretaceous fossil plants from Minnesota, by Leo Lesquereaux: Geol. Nat. Hist. Survey Minnesota, Vol. III, Pt. 1, 1895, pp. 1-22.

[2] Paleozoic fossils in the drift, by F. W. Sardeson: Bull. Minn. Acad. Nat. Sci., Vol. III, 1891, p. 317.

at Fergus Falls large numbers of fossils have been found and identified as Silurian and Devonian species. These formations underlie and are more resistant than the Cretaceous, and hence they must be referred to a subordinate place in our search for the source of the material of the glacial deposits. Since the Cretaceous is presumed still to remain over much of the area, the Paleozoic may also be presumed still to remain beneath it. Upham is confident that it does,[1] and that the bowlders we find represent the disruption of its edges only. Suffice it to say that throughout the entire valley above Courtland no exposures of Paleozoic rocks were seen, and no Cretaceous rocks were noted in place above Redwood Falls.

While the glacial striæ seen on the rocks have been noted from time to time in this geographical sketch, the following table may be found convenient as containing all the observations made in the explorations of the valley by the writer and others, so far as their observations are at hand. The writer is the authority unless another name is given. Starting at Bigstone Lake, the order is down the valley:

Glacial striæ observed in the Minnesota River Valley.

Locality.	Direction.
Sec. 15, T. 121 N., R. 46 W	S. 40° E.
Sec. 21, T. 121 N., R. 46 W	S. 40° E.
Sec. 22, T. 121 N., R. 46 W	S. 40° E.
NE. ¼ SW. ¼ sec. 26, T. 121 N., R. 46 W	S. 35° E.
Bigstone Lake	SE.
NE. ¼ sec. 12, T. 120 N., R. 45 W	S. 45° E.
NW. ¼ SW. ¼ sec 16, T. 120 N., R. 45 W	S. 30° E.
SE. ¼ SE. ¼ sec. 22, T. 120 N., R. 45 W	S. 40° E.
NW. ¼ NE. ¼ sec. 22, T. 120 N., R. 45 W	S. 40° E.
SW. ¼ NW. ¼ sec. 14, T. 118 N., R. 42 W	S. 45° E.
East Granite Falls	S. 45°-50° E. (Upham.)
NE. ¼ NE. ¼ sec. 4, T. 115 N., R. 39 W	S. 50° E.
N. ½ sec. 11, T. 115 N., R. 39 W	S. 50° E.
NW. ¼ SW. ¼ sec. 29, T. 113 N., R. 38 W	S. 52° E.
Posen, T. 113 N., R. 39 W	S. 50° E. (Upham.)
Echo, T. 113 N., R. 38 W	S. 50°-55° E. (Upham.)
NE. ¼ NE. ¼ sec. 32, T. 113 N., R. 38 W	S. 53° E.
NW. ¼ sec. 10, T. 113 N., R. 35 W	S. 60° E. (Upham.)
Beaver Falls	S. 60° E. (Upham.)
NW. ¼ NE. ¼ sec. 30, T. 112 N., R. 38 W	S. 61° E.
NE. ¼ SE. ¼ sec. 6, T. 111 N., R. 38 W	S. 55° E.
SE. ¼ NE. ¼ sec. 12, T. 111 N., R. 38 W	S. 63° E.
E ½ sec. 12, T. 111 N., R. 38 W	S. 50°-60° E. (Upham.)
SW. ¼ SW. ¼ sec. 1, T. 111 N., R. 32 W	S. 48° E.
Ridgely Township	S. 60° E. (Upham.)
NE. ¼ SW. ¼ sec. 35, T. 110 N., R. 30 W	S. 33° E.

[1] Geology of Ottertail County, by Warren Upham: Geol. Nat. Hist. Survey Minnesota, Vol. II, 1888, p. 543.

CHAPTER IV.

GNEISSES.

GENERAL CONSIDERATIONS.

The laminated granitic rocks designated gneisses constitute the great bulk of the crystalline rocks stretching along the bottoms of the Minnesota River Valley between New Ulm and Ortonville and standing in a few isolated knobs in the higher prairie district south and west of the river.

As a rock type, gneiss probably presents more varieties than any other known species. In addition to all the chemical and mineral phases which the granites are known to possess, the gneisses exhibit all the modifications which the lamination of a rock may develop. Structurally a series is recognized from the granitoid masses where only the imagination of the geologist or his observations covering extensive rock areas can distinguish between a gneiss and a granite, to that other extreme where the discrimination between a gneiss and a schist is based on equally uncertain data. As Hager truly says in discussing the granites and gneisses of Vermont: "Cases occasionally occur when it is very difficult to decide whether the rock be stratified or not. Even those rocks which all geologists concede to be granites . . evince such a disposition to split in certain directions that the workmen generally regard them as stratified rocks."[1]

There is scarcely a step in the structural series of gneissic rocks that is not represented by the gneisses of this valley. The granite-gneisses of Ortonville, Yellowbank, and Fort Ridgely, the porphyroidal exposures of Beaver Falls and Odessa, the normal and strongly banded masses at Morton, the schistose bands of many other localities, as along the lake shore below Vicksburg (sec. 29, T. 114 N., R. 36 W.), all express certain well-known phases of this rock type.

Some exposures are intricately contorted and others evenly banded. The rocks of some localities are shattered throughout, and in other localities there are immense areas where for long distances no fault or joint is seen.

In mineral composition there is even greater diversity than in structure. In the valley are hornblende-gneiss, hornblende-biotite-gneiss, augite-biotite-gneiss, biotite-gneiss, and biotite-muscovite-gneiss, with every possible transition stage between them. The chemical composition varies from a highly siliceous to a basic gneiss.

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[1] *Economical geology of* Vermont, by A. D. Hager: Geology of Vermont, 1861, Vol. II, Pt. IX, p. 736.

In using the term "gneiss" to cover rocks with so great a range of structural and mineral characters, it will at once be seen that its application must be much wider than that given it in the early days of geology. Excluding those dioritic and gabbroid rocks which are sometimes regarded as gneisses,[1] there remains the vast series of laminated rocks consisting of feldspar of several species—without exception more than one is present—quartz in one and two generations, the micas or hornblende, or both, and occasionally some other representative of the bisilicate constituents.

The investigations made by the writer show the gneisses of the Minnesota River Valley to be peculiar. They differ from the gneisses of the Muhl circuit, since in that district muscovite predominates in one division and biotite in the other;[2] from the Korean gneisses, which, according to Roth, are to a great extent biotitic and associated with hornblende and other schists;[3] from the pyroxene gneisses of Varberg, which Törnebohm recently described;[4] from those of Scotland, described particularly in their relation to the attending granite by J. J. H. Teall;[5] from the varieties of Vermont gneisses enumerated by Hitchcock;[6] from the gneisses of New Hampshire described by Hawes,[7] and from the hornblendic gneisses of the Farmington Canyon mentioned by King.[8]

The geologic age of the rocks under discussion can only be assumed. The fact that they are geographically isolated from every other district where similar crystalline rocks occur has already been emphasized. The glacial drift everywhere spread over them conceals their relations to the hornblende-biotite-granites of the Sauk River Valley to the northeast, and to the epidote-granites of Ashley and Ward to the north. Their stratigraphic relation to the quartzites of Courtland and southwestern Minnesota has already been pointed out. Cretaceous limestones around New Ulm, and sandstones and shales below Redwood Falls, in the Birch Cooley Gorge, and toward Franklin, lie close to them, if not immediately upon them. They are believed to represent a portion of the vast stretches of Archean rock formations underlying Minnesota and the neighboring States of Wisconsin, Iowa, and the two Dakotas.

By means of artesian-well borings made in many portions of the States named, the crystalline rocks have been discovered and their

[1] British Petrography, by J. J. H. Teall, London, 1888, p. 295.

[2] Materialien zur Orographie und Geognosie des Muhlviertels, Referat, by Hans Commender: Neues Jahrbuch für Mineral., Bronhard, Vol. I, 1885, p. 417.

[3] Beiträge zur Petrographie von Korea, by J. Roth: Rept. in Neues Jahrbuch für Mineral., Bronhard, Vol. II, 1887, p. 104.

[4] Naagra exempel paa pyrorenforande graniter och gneisser, by Törnebohm: Referat, Neues Jahrbuch für Mineral., Bronhard, Vol. I, 1881, p. 70.

[5] British Petrography, London, 1888, p. 326.

[6] Azoic rocks, by C. H. Hitchcock: Geol. of Vermont, Vol. I, Pt. III, 1861, p. 454.

[7] Mineralogy and lithology, by Geo. W. Hawes: Geol. of New Hampshire, Vol. III, Pt. IV, 1878, p. 209.

[8] Systematic geology, by Clarence King: U. S. Geol. Expl. Fortieth Par., Vol. I, Chap. II, Archean, p. 51.

depth from the surface has been measured. In this way it has been found that the Paleozoic rocks of Wisconsin and Iowa form only a thin sheet, from a few feet to a few hundred feet thick, over the pre-Paleozoic rocks beneath. In the Dakotas on the west the gneisses and quartzites slope gradually westward from near the west line of Minnesota beneath the water-bearing Cretaceous sandstones, with their overlying shales, until at the James River Valley at Aberdeen, South Dakota, they are 1,220 feet below the surface. Toward the north also, at Moorhead and at Fargo, granitic rocks are reached at 375 feet. The slope toward the south, beneath the Paleozoics of Wisconsin and Iowa, is shown in a similar manner to be a gradual one. Granitic rocks are reached at 524 feet beneath the city of La Crosse, and quartzite is said to be reached at 768 feet beneath the surface at Spencer, Iowa, while to the east and northeast surface exposures are soon reached in Wisconsin. With such a comparatively extended plain on which the Paleozoic sandstones and limestones were laid down, the formation and deposition of this sediment must have been a process of vast time extent, and it is only natural to find the floor of fresh rock distinguished by very marked irregularities after the scorings of the successive ice invasions.

There is no reason to believe that in any geologic period since Cambrian time there has been any marked or unequal uplifting of this region, but as a vast, central continental plain it has been subject to the ordinary oscillations of level illustrated by those of the Glacial epoch. It is believed that nowhere in the States named—save, perhaps, for a part of the area of the Dakotas and a portion of the Mississippi Valley—does the upper limit of the Archean rocks sink below the present level of the sea.

The metamorphosed condition of the rocks points to an enormous time gap between the close of their building processes and the first deposition of Cambrian sediments on this part of the North American continent. Walcott has placed these first sediments in the Upper Cambrian,[1] while Hall and Sardeson refer them to the Middle Cambrian.[2]

Nowhere have any indications been found that the crystalline rocks can be regarded as altered sedimentary strata, as was recently announced by Director-General Geikie for some of the gneisses of the northeast Highlands of Scotland.[3]

The considerations above given, together with the mineral composition and other lithological characters, lead the writer to the opinion that the ancient gneisses under discussion must be regarded as of Archean age. Indeed, no geologist has thus far placed them in any other division of geological time. Owen, who calls these "the cryst-

[1] Fauna of the Lower Cambrian or Olenellus zone, by C. D. Walcott: Tenth Ann. Rept. U. S. Geol. Survey, 1890, p. 548.

[2] Magnesian series of the Northwestern States, by C. W. Hall and F. W. Sardeson: Bull. Geol. Soc. America, Vol. VI, 1895, p. 170.

[3] Nature, Vol. XLIV, 1891, p. 480.

line and metamorphic rocks," Anderson and Clark, who designate them "the primitive system of rocks," and others, down to Van Hise,[1] place the Minnesota River Valley rocks in the bottom division of the geological series. The term "crystalline and metamorphic rocks" of Owen and the "primitive system" of Anderson and Clark meant the same thing as does the word Archean, first proposed to geologists by Dana in 1874 in his subdivisions of geological time.[2]

The subdivision of these rocks into series of greater or less independence and importance can be made without much difficulty. In traversing them across their strike, as one must in ascending or descending the valley, many modifications of the gneissic type are encountered. These modifications lie partly in the structural phases which have already been pointed out and partly in the lithological characters which are now to be discussed.

Our studies will lead us to the conclusion that we have had under investigation two series of rocks, the one exposed at the two ends of the valley, typified in the exposures at and around old Fort Ridgely and at Ortonville, and the other in the central part, at Granite Falls and at Minnesota Falls. The Granite Falls series is represented by the gneissic exposures in Delhi and neighboring townships (Pl. VIII) and along the bottoms to a point several miles above Granite Falls, in sec. 14, T. 116 N., R. 40 W. (Pl. X). The Ortonville series is represented by the heavy and generally granitoid exposures seen stretching northwesterly from New Ulm to the great rock barrens, reaching into secs. 12 and 13, T. 114 N., R. 38 W. (Pls. IV, V, VI, VII, and VIII). Again, in the river bottoms below Montevideo the same series reappears and continues uninterruptedly to Ortonville (Pls. XI, XII, and XIII). Exposures of the granite-gneisses cover several square miles below the latter place. Their extent and favorable condition for study suggested the name Ortonville that has been applied to the series so extensively developed in the valley. Nowhere do these rocks rest in contact with those appearing in massive exposures around Fort Ridgely, Morton, Beaver Falls, and Montevideo.

In the study of the rock succession represented in the valley, the rock phases will be described according to the petrographical characters. Such a classification will be found exceedingly simple and at the same time progressive. Starting with the massive or granitoid types, the discussion will follow to the schistose and semibasic varieties.

MINERAL CONSTITUENTS OF THE VARIOUS GNEISSES.

Primary quartz.—In many typical hand specimens of the hornblende-biotite-gneisses quartz is the most conspicuous mineral among the constituents. This is noticeably the case in the granitoid gneiss localities.

[1] An attempt to harmonize some apparently conflicting views of Lake Superior stratigraphy, by C. R. Van Hise: Am. Jour. Sci., 3d series, Vol. XLI, 1891, pp. 117-137.

[2] Manual of Geology, by J. D. Dana, 2d ed., 1874, p. 139.

In places among these rocks quartz seems to constitute at least two-fifths of the whole bulk (sp. 5268, 5342). Again, there are isolated areas where the quartz occurs in lenticular masses almost wholly unmingled with other minerals. Typical localities are at Hindarmann's farm (sp. 5183), a mile or so above old Fort Ridgely (sp. 5184 A), near the mouth of Birch Cooley (sp. 5208), and at other places. These occurrences will be discussed in another place under vein material. The usual mode of occurrence of quartz, however, obtains here—that is, as interstitial material generally distributed among the other constituents.

Frequently there lie along the sides of fractures zones of quartz containing cavities, usually filled with liquid but sometimes empty. The origin of the quartz by pressure is thus indicated. As a rule the cavities are in clusters or bands. The quartz is broken up into numerous interlocking individuals, some of which are of large size. The liquid-filled cavities often occur in streams crossing both the quartzes and the adjoining feldspars until they lie scattered across the entire slide (sp. 5237, 5301, 5308, 5344, and others).

Very generally, too, in these primary quartz areas there are numerous inclusions of minute, needle-shaped crystals, which lie in every possible direction, and are too small to be studied with any positive results. They are believed to be rutile needles, both from kindred observations in other localities and from the fact that Prof. James A. Dodge, of the University of Minnesota, made a very careful qualitative examination of some of this quartz from Hindarmann's place (sp. 5183, 1,750 paces N., 1,750 paces W., sec. 22, T. 111 N., R. 32 W.) and discovered in it distinct traces of TiO_2.

In many places throughout the valley, particularly around Fort Ridgely and Ortonville, the quartz has a remarkably opalescent, bluish aspect, giving a peculiar skimmed-milk appearance to the mineral. The quartz is white, and at the same time has a watery, limped look not usual in milky quartz. Occasionally an amethystine tint is also present. The opalescence is seen in the gneissic quartz and in the vein-like segregations alike. Where there is the highest degree of opalescence the needle-shaped crystals mentioned are most abundant. The conclusion was therefore drawn that the opalescent character depends on the abundance of the mineral rutile within the quartz.

Such inclusions in the quartz as have been pointed out occur only in those large yet allotriomorphic individuals with which all the gneisses of the valley abound. The individuals, usually regarded as primary, may or may not be one of the original mineral constituents of the rock. Their existence and present condition afford no evidence touching the origin or development of quartz as an essential constituent mineral. The quartz might have been present at the original crystallization of the rock or it might not have been. Time and the alteration processes to which the rocks have been subjected might have developed large and numerous areas of this mineral as it has of others.

Secondary quartz.—In addition to the large areas of quartz just noted there are almost always present segregated areas of a finely crystalline phase of this mineral. These areas are at times around the borders of the feldspars, again, in the midst of the feldspars themselves, especially within the orthoclase and microcline individuals, and at other times in the areas of altered basic constituents intermingled with the hornblende, biotite, magnetite, etc., which have resulted from the breaking up of the original mineral constituents of the rock. In these areas the quartz exists in very minute individuals, highly transparent, and, under crossed nicols, brightly polarizing. They are sutured together, and are exceedingly free from impurities of every kind.

Three forms of secondary quartz are noticeable:

1. Fine, granular segregations, perfectly transparent, compact, and almost wholly free from impurities.

2. Fine, brightly polarizing, isolated granules and pegmatitic areas in the midst of and around the feldspars. They occur more frequently associated with the potash feldspars, i. e., orthoclase and microcline, than elsewhere, although they are frequent in individuals of the albite type.

3. Vermicular quartz in and around the feldspathic individuals, more particularly those which show strong evidences of alteration.

Of peculiar interest in these granitoid rocks is this vermicular quartz, which is very widely distributed. As a rule it is microscopic, very rarely appearing in areas sufficiently large to be detected with the unaided eye. Almost without exception its secondary origin is evidenced by its distribution, for it is found within the boundaries of the older rock constituents, particularly the feldspars.[1] Within this group of minerals no particular preference seems to be shown; it as frequently invades orthoclase or microcline as it does the plagioclastic species. The contorted, vermicular passages through which the silica has made its way into the corroded constituents can be seen on Pl. XVIII, *B*, taken from the hornblende-biotite-gneiss (sp. 5396) of sec. 30, T. 112 N., R. 38 W., the town of Vesta, in the prairie region of western Redwood County.

Feldspars.—This mineral group is represented by several members. There is no apparent law of occurrence; scarcely a sample was taken that did not show several species. In few places did the rock show any single species as especially predominant.

In size of individuals there is the greatest diversity, the apparently primary ones reaching in places the size of several inches, while others are very small. The former are usually filled with the products of their own decomposition, mingled with and modified by those of the other mineral constituents of the rock. The outlines of the individuals "of primary consolidation," as Fouqué and Lévy call them,[2] are seldom

[1] Minéralogie Micrographique, by Fouqué et Lévy, Paris, 1879, p. 193.
[2] Op. cit., p. 151.

clearly defined. They usually merge into a mingled mass of quartz and feldspar individuals or into a zone of quartz alone.

At a few places in the valley—for instance, around Ortonville—orthoclase seems to have suffered alteration more than any other feldspathic constituent. Yet amid all the changes it has undergone this mineral has not completely lost its identity.

Microcline plays a very important part in the constitution of these gneisses. It is frequently in porphyritic crystals an inch or more long. The surface usually has a pale reddish tint, and the fine fractures are coated with limonite. In point of quantity microcline seems greatly to exceed orthoclase in this group of gneisses.

While orthoclase and the plagioclases are, as a rule, more or less altered to kaolin, muscovite, and other products, with few exceptions the microcline areas are fresh and transparent. In this respect these rocks are no exception to the condition observed in northern Michigan. Where the microcline has altered to a preceptible extent it contains many small areas of clear quartz. These areas are either closely compacted or in the vermicular forms.[1] Wherever the feldspars are secondary—and such places are numerous—microcline takes the foremost place in quantity as well as in the development of its characteristic features.

In its distribution microcline accompanies both orthoclase and the acid plagioclases. Usually the boundaries of the contiguous individuals are sharply defined, yet not infrequently the sharp definition disappears and the line of demarkation can not be seen. Such a merging of an oligoclastic individual with microcline is seen in Pl. XIX, *B*, from a specimen taken below Ortonville. Again the merging of the microcline into orthoclase is seen. Several slides from fresh specimens of gneiss show orthoclase grains of large size surrounded on two or more sides with microcline. The two feldspars grade into each other so imperceptibly that the boundary between them can not be followed. The former thus constitutes the core, and the relative situation strongly suggests some genetic relationship between the two.

It still more frequently happens that in the midst of large individuals of orthoclase or plagioclase bright, fresh grains and granules of microcline appear. (Pl. XX, *B*.) Less frequently similar small patches of other feldspars, and even other mineral species, are seen. The outlines of these individuals are well defined. All the areas of microcline found within a single individual of orthoclase or oligoclase extinguish together, showing their possible connection in the third dimension. While the relationship in position holds good under the circumstances named, the clusters of microcline, orthoclase, plagioclase, and quartz, so frequent in more altered material, show no such parallelism. Yet it is by no means clear that the smaller included individuals are secondary to the larger ones. They may represent minute quantities of micro-

[1] The greenstone-schist areas of the Menominee and Marquette regions of Michigan, by G. H. Williams: *Bull. U. S. Geol. Survey* No. 62, 1890, p. 111.

clinic material caught up in the original individualization of the rock constituents, and maintained to the present time in their mineral integrity. Excellent illustrations of this phase of mineral association are shown in specimens 5315, 5320, and many others (see Pl. XX, *B*).

Several varieties of plagioclastic feldspars are present in varying quantity. At one extreme, in the large number of individuals measured, the extinction angle along the twin lamellæ is between 1 and 4 degrees, pointing to a soda feldspar.

The microcrystalline feldspars, while occasionally appearing in the larger individuals of feldspar, are as a rule distributed among the grains of quartz, also microcrystalline. They are always much more transparent and more strongly polarizing than the primary individuals just described; in optical characters they are almost identical with them.

Some features shown by the microcrystalline feldspars are marked. For instance, the outlines of all the grains are sharply defined by contact with neighboring grains. Occasionally an interlocking of material occurs, yet this habit is not so common as among the quartzes. Very few impurities or intergrowths are seen in these areas, and they are poor in bisilicate individuals. Accessory minerals are also rare, apatite being almost unknown in these portions of the slides.

Biotite.—This mineral is everywhere present and often bears unmistakable evidence of being secondary. As a rule it is associated with hornblende. The latter mineral occupies the major place among the bisilicates in the sections cut from the freshest rocks; more altered rocks show the biotite and hornblende in about equal proportions; and samples taken from those portions nearest the surface and most thoroughly altered show little hornblende, but biotite is plentiful. In these weathered portions the biotite is well individualized, yet even here the areas are either small in size or complex in structure. Where the areas are not complex they are noticeably scattered through the rock, much more than are the individuals of quartz and the several feldspars.

The general characters of biotite so often described obtain here; therefore little need be said on that subject. Several specimens show a marked radial arrangement of the biotite. The individuals appear decidedly acicular in form, and shoot out from a common center in all directions, forming rosettes of long, slender crystals. A well-marked porphyritic gneiss (sp. 5262) from the middle of the valley, shows in one of the quartz individuals a decidedly rosetted arrangement of the biotite (Pl. XX, *A*).

Inclusions of rutile, or some mineral similar in habit, are rather frequent in the biotite of the most altered gneisses. As a rule this mineral assumes the form or position of a sagenite web, but many needles were also noted, identical in their external characters with those seen in the quartzes and feldspars associated with the biotite.

hornblende lying in contact with them assumes the shape thus determined. Occasionally smaller individuals of hornblende are well formed and show very complete sections of crystals, but this is a rare phenomenon. In color there is much variation, the green usually prevailing. In the gneisses, as a rule, the hornblende is unusually free from inclusions, although in the gabbro series it abounds in them, as will be stated in Chapter V. Where mineral impurities occur, epidote, rutile, and biotite occupy the leading place.

Very frequently a close relationship is seen between the biotite and the hornblende. As has already been mentioned, the last-named mineral shows every indication of secondary origin. It lies in clustered aggregates, and seldom is an area composed of a single individual. The hornblende individuals bear no evidence, in their association and structure, of being primary. They can not be found in these rocks associated with some pyrogenic constituent and the steps of change from the latter be followed step by step, as can be done in the gabbroid granites of Rhinelander, Wisconsin, and in the hornblende-biotite-granites of central Minnesota; but in studying the series as a whole, from one end of the valley to the other, every stage in the alteration process can be seen, from the fresh augite individuals to those firmly knitted, brown hornblende areas which represent the mature stage of this mineral. From the general composition of the hornblende clusters, from the association of other minerals, and from the presence among them of secondary quartz and feldspar granules the secondary origin of the hornblende is most confidently assumed.

Again, among these gneissic rocks phases, with many intermediate steps, appear, in the one of which the genesis of the hornblende can not be read, in the other of which it can be read with high assurance of correctness. The relations between these two types are so close, and their mineral conditions are so nearly identical, that one can not well avoid carrying the conclusions reached in the study of the latter phase over into interpretations of the former, and asserting the same conclusions in respect to it. Hence the writer has reached the conclusion that there is no such thing in the Minnesota River Valley as original or primary hornblende. For other portions of the Northwest, where the so-called Archean rocks appear, investigators have announced similar conclusions. For instance, Irving stated, while studying the Wisconsin Valley:

"Mr. Van Hise's study shows now that augite, so far from being a stranger to such rocks as gneiss and granite, is nearly as common a constituent, so far at least as this region is concerned, as hornblende or mica, and that all of the hornblende of the rocks of this region is but altered augite."[1]

Wadsworth, who examined the gabbros of the Northwest, believed "all the hornblende seen . . . to be secondary . . . In color

[1] Geology of Wisconsin, Vol. IV, Part VII, 1882, p. 714.

it varies from a light or yellowish green to a dark brown or yellowish brown . . . the darker stages being simply the more perfected condition of the greener or uralitic stage."[1] Lawson, for the Rainy Lake region, recently studied by him, said that "it seems not improbable that all the hornblende of the hornblende-syenite and granite [granite gneiss] of this region is of secondary origin."[2] Further, Geo. H. Williams, Judd, Schuster, and many others have noted the alteration of augite into hornblende in other parts of the world. Laboratory experiments[3] have been made, extending through a long series of years, in endeavors to show that hornblende represents the stable molecular arrangement of this already much-studied metasilicate compound.

The hornblende and biotite are, in all the granitoid gneisses sampled, extremely sparse. The only exception is seen in the rocks of the bottoms just above old Fort Ridgely, where a liberal sprinkling of hornblende and biotite can be seen over two or three areas. Basic inclusions were found in the rocks in their ordinary phases, while none were found in the acidic gneisses. In sec. 2, T. 11 N., R. 33 W., there are a number of inclusions of various sizes, well defined, schistose in structure, rather fine in texture, and a hornblende-biotite-schist or gneiss in mineral composition.

Augite.—In their present altered condition the normal gneisses of the Minnesota River Valley carry augite in only two or three localities, so far as the gathered hand specimens show.

Of these localities, the first to be mentioned is that around La Framboise's and Hindarmann's farms, below old Fort Ridgely, in secs. 15, 16, 22, and 23, T. 109 N., R. 32 W. (sp. 5191, 5192, 5721, 5722). The second locality is at Granite Falls, in sec. 31, T. 116 N., R. 40 W. (sp. 5768 and 5769).

Only a small quantity of augite is present in the freshest of these exposures, and even this shows partial alteration, save in one or two slides from the La Framboise locality. Two or three hand specimens from this place present the alteration of augite into biotite without disclosing the intermediate stage of hornblende-building. At Granite Falls the alteration into fibrous hornblende of some mineral which is presumed to have been augite has already been discussed. It may be remarked here that in all the slides cut from gneissic rocks where augite is present the proportion of basic minerals is extremely small.

Pyrite is to be seen nearly everywhere, but, as a rule, it is sparse. Under the railway tracks near Odessa, sec. 31, T. 121 N., R. 44 W., there is a comparative abundance of iron sulphide, probably marcasite. It occurs in segregations of small size. Some blocks have been blasted out and their surfaces are stained with iron rust from the alteration of

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[1] Preliminary description of the peridotytes, gabbros, diabases, and andesytes of Minnesota, by M. E. Wadsworth: Geol. Nat. Hist. Survey Minnesota, Bull. No. 2, 1887, p. 66.

[2] Report on the geology of the Rainy Lake region, by Andrew C. Lawson: Ann. Rept. Geol. Nat. Hist. Survey Canada, 1887-88, p. 125F.

[3] Geo. H. Williams has enumerated the chief of these. On the paramorphosis of pyroxene to hornblende in rocks, by Geo. H. Williams: Am. Jour. Sci., 3d series, Vol. XXVIII, 1884, p. 259.

these segregations. This alteration is so rapid that only on comparatively fresh surfaces can any of the iron sulphide be seen. Numerous cavities on the older surfaces, and the deep stains of iron rust, point to the former existence of the compound. In other localities clusters of pyrite crystals are to be seen, but nowhere in sufficient quantity to deserve particular notice, and probably in no place save the one mentioned in such quantity as to have a deleterious effect on the stone for economic uses.

Magnetite appears in many slides, but nowhere in quantity visible to the unaided eye. In its occurrence it bears evidence of secondary origin. It usually lies clustered about the spots where bright-green hornblende and minute, clear grains of secondary quartz are segregated. In several sections beautifully segregated masses occur, notably in the larger dike west of Granite Falls (sp. 5286).

Hematite is present in about the same quantity as magnetite. It appears in the surficial, most-altered portions of the rock. Where the rock crumbles the heaviest accumulations of this mineral appear. In such situations the cleavage planes of the feldspars are stained, as well as the opened contact zones between these and the other constituents. More rarely the hematite stains hornblende and chlorite clusters so that the appearance is that of a fibrous or radiated hematite.

Limonite is distributed as is hematite. Indeed, these minerals are usually distinguished by their colors. So far as their associations go, hematite and limonite merge into each other in many cases in such a way as to suggest that the only difference between them lies in the hydrated condition of the latter through the influence of percolating waters.

Ferrite.—Occasionally around the areas of hematite one sees a whitish or light-brown, finely granular, closely packed iron substance, sometimes arranged in well-defined areas, as if the material were a pseudomorph after some preexisting mineral, now totally removed. Not infrequently this preexisting mineral would seem to be magnetite. From the difficulty found in separating it from a stained kaolinic decomposition product, almost everywhere abundant in the much-altered gneisses, no satisfactory determination of the mineral can be made, and so it is given the general name *ferrite.*

Rutile is present in minute, needle-shaped crystals which penetrate all the leading constituents of the granitoid gneisses. It was only in the biotite that any regularity whatever was noticed in the arrangement of these crystals. Here occasionally a strongly marked network of needlelike crystals can be seen in such sections as are cut at a low angle to the cleavage. In the quartz rutile is a most frequent impurity, especially around Fort Ridgely and Ortonville, as has been elsewhere stated.

Apatite, in the usual needles, is a frequent accessory. Often a broken condition indicates great pressure exerted at some early or middle *transition stage* in the alteration of the rocks.

Kaolin.—This is an extremely interesting alteration product. It is very general in its distribution. The freshest specimens disclose only traces, but the gneisses of Birch Cooley, Redwood Falls, and thence locally as far as Granite Falls, are so completely broken down as to be soft and unctious to the touch. Here kaolin is one of the two or three abundant secondary minerals present. Between those two extremes—the fresh, firm rocks on the one hand and the completely decomposed varieties on the other—lie numberless phases of alteration. Ordinarily the kaolin occurs in minute elongated leaflets, which resemble very closely in all outward characters minute folia of muscovite. They are very clear, white, and strongly polarizing. Indeed, in many cases it is more than probable that muscovite and kaolin are intermingled.

Epidote is a mineral of no small interest in the study of these rocks. In all the sections examined not one crystal of this mineral was seen. There are two modes of occurrence:—the granular, where the mineral lies in isolated or segregated individuals of varying size, from the extremely minute to those which compare in area with those of quartz and feldspar; and the radial, where from a central point radiating grains shoot out into the substance of the host, giving a bright, rosette-like field in polarized light.

Epidote is singularly free from inclusions. Rarely fluid inclusions can be seen. Here and there an intergrowth with other minerals was noted. Nowhere does epidote present the features of a primary constituent of the rocks carrying it. It is most abundant in the extremely weathered rocks. Thus beneath rock surfaces long exposed to the weather and in proximity to thin bands or veins in the gneissic masses epidote should be expected; but in the deeper alterations, like those which have resulted in the kaolin of Birch Cooley, only occasional traces of it are to be found. It is sometimes present in the midst of feldspar individuals, much altered from their original chemical and physical conditions.

Chlorite also is an accessory. Although rather frequently met with, there are only two or three localities where it is sufficiently abundant to receive special consideration. On Tracy's farm, sec. 10, T. 112 N., R. 34 W., is the most conspicuous locality found. Here one knob of gneiss with coarse and indistinct foliation, somewhat jointed, with large feldspar individuals, and abounding in dark-colored inclusions, exhibits the most beautiful individuals of chlorite thus far seen by the writer in Minnesota. Radial areas and chains of hexagonal plates are beautifully developed, and show the characteristic optical characters of the mineral. (Pl. XVII, *A*.) It seems to spring from the decomposition of both basic and feldspathic constituents, although it is doubtless true that the basic minerals play the leading rôle.[1] It is associated with quartz, and lies usually in clusters and bands of secondary formation.

[1] Compare Rosenbusch, Physiographie d. pet. wichtigen Mineralien, 3d ed., 1892, p. 598; also ibid., Iddings's translation of 2d edition, 1888, p. 188.

The other localities in the valley where chlorite appears are the neighborhood of old Fort Ridgely, Redwood Falls, Beaver Falls, and at several localities around Granite Falls and Minnesota Falls. At all these places both the hexagonal plate and the radial cluster are absent. Occasionally a large area having the ordinary characters of hornblende has the optical reactions of chlorite; again, small isolated individuals are discovered.

HORNBLENDE-BIOTITE-GRANITE-GNEISSES.

In ascending the Minnesota Valley the first gneissic rocks one meets are granite-gneisses. There are four areas where the rocks are more distinctly granitoid than elsewhere in the valley: Around old Fort Ridgely (Pl. IV), below Ortonville (Pl. XIII), on the "rock barrens" in T. 114 N., Rs. 37 and 38 W. (Pl. VIII), and around Vicksburg, 5 or 6 miles southeast of the "barrens" and practically midway in the valley between New Ulm and Ortonville (Pl. I). In all the areas named the granite-gneisses carry inclusions, sometimes of large size, of schistose rocks. They are, save at Ortonville, in contact with the ubiquitous gabbroid schists. Everywhere within them are seen numerous quartzose and granitic veins. The granite-gneisses are everywhere hornblendic, and usually carry so much of that mineral associated with the biotite that they are hornblende-biotite-gneisses.

ORTONVILLE AREA.

Beginning a little below the city of Ortonville, and extending for 10 or 12 miles down the Minnesota River Valley, lies a series of knobs of granite-gneiss. There are places where for a mile and more no bed rocks can be seen, the débris of the ancient River Warren and of the Minnesota having covered them. The largest exposures are several hundred paces in extent, and occasionally reach heights of 50 to 75 feet above the bed of the river. The map, Pl. XIII, locates the ledges with sufficient detail save when some special character is to be noted. The peculiar billowy aspect produced by the glaciated surfaces of these gneissic rocks immediately below Ortonville has already been mentioned; so, too, has the direction of the glaciated striæ, together with the morainic movements which produced them. In structural characters there is some variation. On the ledges nearest Odessa there is seen a massive structure which only occasionally discloses a genuine lamination. Yet as one looks at the polished surfaces of the rock a distinct parallelism in the position of the idiomorphic feldspars is seen.

Passing eastward to the series of exposures between the village of Odessa on the north and the Yellowbank Creek on the south side, one finds a distinct gneissic structure prevailing. The strike of the laminæ is, on the most typical exposure, nearly N.–S., with a dip of from 40° to 45° E. (sp. 5320, 1,400 paces N., 600 paces W., sec. 30, T. 121 N., R. 45 W.). The strike and dip cited for that exposure do not, however, everywhere

prevail. A variation to a strike NE.–SW. can be seen within two-thirds of a mile, and doubtless exists much nearer. Still farther to the east and south are exposures showing conspicuously the parallelism of the idiomorphic feldspars mentioned as so plainly seen near Ortonville. Under the railway track, near milepost 168 from Minneapolis, on the Chicago, Milwaukee and St. Paul Railway, lies a considerable mass of granite-gneiss (sp. 5312, 5313). It contains inclusions of a schist, and is interlaminated with a more distinctly gneissic type of rock. It has been quarried for trestlework, and a good view of the fresh surface can be had. A mile or so to the west, and just south of the railway, lies another low exposure of very similar habit. The mineral constituents are here very fresh. One mile south of this spot, in a bend in the river, are several exposures of a similar granitoid type, carrying considerable biotite. The rock here has a reddish color and is rich in feldspars. The direction of these feldspars is NE.–SW., with scarcely a trace of mineral segregation into gneissic laminæ. Yet only a few hundred paces to the southwest a knob of sharply gneissic rock stands up in the bottoms. The individuals of feldspars—there are several species in these rock masses—are quite fresh, and their outlines are well-defined against the matrix. All species alike show the usual inclusions, even with the unaided eye.

In the old river valley, a mile and more to the south of the Yellowbank Creek, is a series of exposures. The most southerly knobs are almost entirely devoid of foliation; for instance, those on the Parmenter farm, in sec. 22, T. 120 N., R. 45 W. (sp. 5337), and another a half mile west (sp. 5336). Some show a parallelism of the feldspars (sp. 5338), while others exhibit interlaminated schists and a varying gneissic condition of the acidic rock.

The easternmost exposures represented on the map (Pl. XIII) consist of a pair of knobs of considerably finer grain than the gneisses to the west. A sharply defined parallelism marks a NE.–SW. direction, with a dip to the SE. of 40° to 45°. Smoothly glaciated surfaces of some of the highest knobs show striæ pointing S. 30° E. to S. 40° E., which is the general trend of the valley in this upper portion.

The jointing of these rocks was everywhere noted. Broadly speaking, there are two systems of joints, one having a NE.–SW. direction, and the other a NW.–SE. direction; but there are minor joints. Around Ortonville joints are comparatively rare. The view of Baxter & Son's quarry, shown in Pl. XIV (p. 40), gives an accurate representation of the massive character of the granite-gneiss at this place.

In color the granite-gneisses of the upper valley are a light red. Pl. XVI, *A*, shows the color and texture in natural size. Exposure modifies its tone somewhat, but where river silt and glacial débris have kept the surface covered it is strikingly fresh. Examination shows that the color is due to films and flecks of ferric oxide infiltrated along the contact surfaces and cleavage planes of the mineral grains. The origin

of the ferric oxide is not so clear. The first source to suggest itself is the covering of glacial drift, which everywhere contains a perceptible percentage of this compound. But in the deeper parts of the extensive quarry at Ortonville the rocks are as brightly colored as near the surface.

The microscopic characters of these rocks have already been briefly described in this chapter.

Ordinarily a medium texture prevails. This becomes somewhat coarser in certain lenticular areas which are doubtless due to a segregation process. At other places rather finely crystalline, almost microcrystalline, patches are seen.

Feldspar is the leading mineral. The larger individuals are mostly idiomorphic, frequently affording bright cleavage surfaces and minor fractures. Their transparency is so great that they remind one of shattered quartz. Some mineral inclusions are present, the most frequent being quartz, in spherical and elliptical grains, and other species of feldspar. For instance, within the oligoclase areas are small, fresh microcline individuals. Somewhat rarely the polysynthetic twinning of the triclinic individuals is clearly seen. The alteration products of the feldspars, save the quartz just mentioned, can not be seen with the unaided eye. Where the quartz is of the first generation it has the skimmed-milk blue color so common in the granitoid rocks of the entire valley. A peculiar opalescence results from this, which is noticeable on fresh fractures. In the granite-gneiss of ordinary texture quartz of the peculiar opalescent phase is abundant. In the finest-grained specimens the quartz is subordinate, the feldspars, with a few areas of biotite, making up the mass of the rock. Where the rock becomes coarsely granular or pegmatitic, quartz assumes an increased importance. In these places it is more transparent than is usual. It extends in irregular bands and masses between the feldspars, and thus plays the rôle of a matrix.

The bisilicate constituent, biotite, is not a conspicuous one. In many instances hand specimens fail to disclose its presence. Again it appears in such quantities as to make the darker-colored bands giving the foliated condition seen on many exposures.

Hornblende is not abundant in the Ortonville exposures. It is seldom seen in the surface specimens, and plays a very unimportant part in those taken from the depth of the quarry. Enough is present, however, to give a hornblendic character to the rock. It is usually scattered about in isolated grains. An apparent exception is seen in the clustered condition of the granules in the rare bisilicate nodules. Here the hornblende and biotite are mingled in irregular and thickly strewn folia, all assuming one general direction.

The leading accessory mineral in the granite-gneisses of the upper portion of the valley is an iron sulphide. Yet even this mineral occurs only rarely around Ortonville or south of the Yellowbank. At the

railway cut in sec. 31, T. 121 N., R. 44 W., it is more plentiful. When blocks have lain exposed to the air for some time heavy stains of iron rust appear. From the readiness with which the sulphide decomposes it is believed to be marcasite rather than pyrite.

A single chemical analysis of the Ortonville granite-gneiss was made by Mr. A. D. Meeds, of the University of Minnesota. The results confirm those of the microscopic examination as to the nearly equal proportions of potash, soda, and lime feldspars, the sparse distribution of the bisilicate constituents, and the comparative richness of the rock in quartz.

Analysis of Ortonville granite-gneiss.

Constituent.	Per cent.
SiO_2	74.40
Al_2O_3	14.06
Fe_2O_3	3.84
FeO	1.23
CaO	1.73
MgO	0.29
K_2O	1.83
Na_2O	2.17
H_2O	0.26
Total	99.81

VICKSBURG AREA.

Around Vicksburg for several miles there lie huge masses of granite-gneiss. In places a very massive appearance is seen, and again a distinctly foliated condition prevails, where great contortion characterizes the surface. There is almost no interruption in the occurrence of exposures as one approaches the Vicksburg ferry from Redwood Falls. Some of the exposures stand high above the river bottoms, reaching well toward the height of the bluffs of glacial débris, and others are low in altitude and insignificant in area. Strike and dip here, as everywhere else, vary considerably. In sec. 13, T. 113 N., R. 36 W., a reddish, clearly foliated gneiss (sp. 5384) of medium texture strikes N. 80° E. and dips 30° S. The outcrop stands on a bench in the bluff, and reaches an altitude of 45 to 50 feet above the bottoms through which the present river has cut its channel. The chief mineral constituents of this rock are quartz and microcline. Other feldspars are extremely sparse. Quartz is present in at least two generations. The few small areas of hornblende are partially chloritic, and in nearly every instance carry minute grains and needles of what was regarded as titanite. The rock shows evidence of alteration of its feldspars and bisilicate constituents. Some of the more-altered feldspars of the ancient generations contain small folia of secondary muscovite.

FORT RIDGELY AREA.

Opposite New Ulm, in sec. 27, T. 110 N., R. 30 W., is a granite-gneiss which is weathered to an extent much beyond that of the ordinary gneisses of the valley. This is due largely, no doubt, to its protected position at a lower level than the beds of basal conglomerate lying in its immediate neighborhood. An apparent bedding prevails, dipping 15° to 20° toward N. 50° E. The jointing is extremely marked and the rock, as a whole, is greatly shattered. The habit of the rock is porphyritic, orthoclase crystals being often an inch or two in length. They crumble easily. The red color characteristic of this group of exposures lies in the feldspars. Considerable white quartz is seen in the form of veins. These veins are, as a rule, lenticular in shape, yet sometimes they are in narrow, tortuous bands. The basic constituents consist largely of hornblende, with occasional grains of epidote. The quantity of biotite present is small, and only a few small folia of muscovite were seen.

In the neighborhood of old Fort Ridgely the granitoid gneisses are much fresher, firmer, and more massive than in the exposures near New Ulm. At the old ferry and ford, where some years ago quarrying was done for the barracks at the fort, and a little farther up the river, on the line between secs. 1 and 2, T. 111 N., R. 33 W., lie extensive exposures. The rock shows a lamination in the somewhat rare bands of more basic material and in the arrangement of the large porphyritic feldspar individuals (sp. 5415). While the rock shows in places considerable contortion, the general direction of the laminæ is N.-S. The dip is westerly, averaging 50°. The red color which here largely prevails is due to a staining by ferric oxide which has penetrated the cleavage crevices of the feldspars.

Both original and secondary feldspars are present. In many original feldspar individuals the inclusions are so large that they can readily be seen with the unaided eye. They are chiefly granules of quartz, hornblende, and biotite, although some interesting intergrowths of the feldspars were seen (sp. 5187, 5188). Frequently the sides and ends of the idiomorphic feldspars are corroded to such an extent as to show marked irregularities in outline. There is little orthoclase, the primary and in large part idiomorphic individuals which the rock contains being mostly microcline and one or more plagioclastic varieties. In size they are frequently an inch or more in length. The characteristic crosshatching of the microcline is sharply drawn, few individuals being so decomposed as to have the marking obliterated. Frequently crystals show beautifully both the Carlsbad and the polysynthetic twinning. In places there is a narrow reaction rim around these microclines as they come in contact with the albites and quartzes. As the result of a number of measurements, the triclinic feldspar is found to vary between 1° and 12° in extinction angle, and is therefore regarded as oligoclase albite. It shows more alteration than the microcline.

The genetic relations of the two varieties were not studied at this particular locality. The twinning striæ are very fine and are often considerably altered along their boundary edges. Instances are noted where half of an individual is strongly twinned and the other half is entirely free of twinning striations. Other cases occur where on either side of a feldspar area the strong crosshatching of microcline can be seen, while the middle part of the grain bears every evidence of orthoclase.

The secondary feldspars consist of small, transparent, brightly polarizing areas, and are of very frequent occurrence in all varieties of the mineral. These secondary individuals are usually free from inclusions. They are arranged in strings and bands in the midst of the interstitial matter which surrounds the minerals of primary consolidation.

Quartz occurs in two generations. Biotite and hornblende are present in nearly equal proportions, the former in much better-defined areas than the latter. In many of the hornblende areas there lie many granular inclusions of an opaque material which bears every evidence of secondary origin. Its nature could not be clearly determined; it may be pyrite. Cubes of pyrite are occasionally seen. Sphene in small quantities was noted. In the areas once occupied by the primary basic constituents are clustered hornblende granules mingled with secondary quartz, biotite, and some opaque material, probably either magnetite or pyrite. The position and associations of these granules suggest their derivation through the alteration processes which have obliterated the original minerals and made possible the nests of clustered secondary minerals.

Veins or lenses of quartz were noticeable in one or two exposures, particularly at 1,500 paces N., 750 paces E., sec. 2, T. 111 N., R. 33 W. They vary in width from a fraction of an inch to 4 and more inches. Horizontally they rarely extend more than 6 or 8 feet. Their general direction is N. 65° W. The quartz of these veins is somewhat opalescent, although less so than in the veins crossing the augite-gneiss at La Framboise's and Hindarmann's farms 5 miles down the river. This character is due, doubtless, to the minute crystals regarded as rutile which abound in this mineral. Jointing is very conspicuous in the neighborhood of Fort Ridgely. Upon the mass just located conspicuous joints run N. 80° W. across the water-eroded surfaces. They dip southward at an inclination of 65°. Another system of joints, at right angles to the first, dips westward at the same angle, viz, 65°. Joints with similar directions appear at the old Government quarry in the same section and only 300 paces away to the northeast.

Along what seems to be a boundary between the dark-colored and reddish phases of these gneissic exposures lie several interlaminated masses of a hornblende-biotite-schist. These masses vary greatly in size, some of them being no larger than hen's eggs, while the largest extended so far downward and under the turf that its boundaries could

not be determined. The texture of these inclusions is medium; their structure is distinctly schistose. As they weather at the surface they seem to bleach, through the alteration of the dark-colored constituents. These inclusions occur in many other places over the surfaces of these exposures than at the contact zone named; yet along this zone they seem to be segregated. The contact between the inclusions and the granite-gneiss containing them is sharply drawn. A porphyritic condition of the rocks is elsewhere shown through the development of the feldspars. So far as the basic constituents appear to the naked eye, they are finely granular and lie in the angles and along the contact zones of the feldspars. The quartz areas, wherever they can be seen, assume a like position, but this position is noted in the clusters of grains as they lie in the rock rather than in the direction of the crystallographic axes of the individuals.

AUGITE-BIOTITE-GRANITE-GNEISSES.

LA FRAMBOISE AREA.

In several sections around La Framboise's farm, 15 miles in an air line northwestward from New Ulm, occur many large masses of a fresh, firm, granitoid gneiss. Near the stage road, and just under the projecting morainic northeast wall of the valley, stands a very siliceous red rock (sp. 5193). The whole exposure is shattered into rhomboidal blocks by joints running N. 75° E. and N. 10° E., the former set dipping 60° SE. and the latter 70° SW. The lamination of the rock, which is very obscure, strikes N. 20° to 30° W. and dips at an angle of 20° S. Toward the river the rocks assume a grayer color and are much less shattered. Their surfaces, which are waterworn and not glaciated, are grooved and undulating, and disappear at a gentle angle beneath the turf. Yet several abrupt faces 30 to 50 feet high show considerable erosion. The texture is medium, but it varies in places to a finely granular, granitic type. Microcline individuals several inches across are met with. Inclusions of the gabbroid rocks also appear, with sharp contacts wherever contacts can be seen, but their area could not be made out, owing to the covered condition of the rocks. A banded structure appears at times, but the usual evidence of gneissic character is the parallel arrangement of the constituent minerals, particularly the feldspars.

At Hindarmann's farm, a half mile west of La Framboise's, a distinct lamination is developed through the segregation of biotite. More rarely, too, a lamination is produced by the development of lenses of quartz in the shape of thickenings of siliceous veins. In color the more laminated portions of the exposures are the darker, the color appearing to lie as much in the feldspar as in the quantity of biotite and its representative. Where the color is red, it is due to infiltrations in the interstices of the feldspars and in the crevices between the feld-

spars and the quartzes. The gray color varies with the condition of the feldspars.

A microscopical examination shows these granitic gneisses to be pyroxenic, and that the pyroxene is to a considerable extent hypersthene. This constituent occupies but a small place in the mineral composition of the rock. Only now and then will a section show its presence. The grains are small and irregular. On the cleavages and other fractures of the grains alteration has changed the pyroxenic material to a fibrous biotite. Rarely the product of the alteration is a hornblende, and in two or three places chlorite was seen. This pyroxenic constituent is of two kinds, apparently about equal in quantity, one of which shows more or less dichroism (depending on the thickness of the section), a parallel extinction, and the sharp prismatic cleavage of hypersthene; the other appears in more or less rounded grains, irregular cleavage, little or no pleochroism, and with the high extinction angle of augite. The alteration products of the two minerals seem to be identical, their color and degree of transparency being about equal. Inclusions, except as they bear some relation to the alteration processes, are very rare and insignificant. Surrounding most of the pyroxene grains of both kinds are the alteration products, biotite and small, brightly polarizing quartz grains, with occasionally some minute individuals of hornblende.

Several varieties of feldspar are found in the rock. The plagioclases, when measured in the zone, all exhibit the low extinction angle of the albite end of the series, from 2° to 10° being the usual measurements. The plagioclase seems to show more alteration than the orthoclase and microcline. Cloudiness generally obscures the twinning planes, and areas of clear quartz of minute size frequently stud their surfaces, derived, apparently, through the decomposition of the feldspar areas in which they lie embedded. Microcline is present in many large, well-defined individuals. More rarely areas show the optical characters of orthoclase. These two varieties are free from alteration phenomena, yet they exhibit undulatory extinction to an unusual extent, and in places (sp. 5179) induced cleavage phenomena are disclosed.

Quartz plays an important rôle. The larger and more conspicuous individuals exhibit large numbers of liquid inclusions and many long, needlelike crystals of rutile. This last-named mineral is found in large quantities in the feldspars also. In many areas in proximity with the feldspars a microcrystalline condition of the quartz is rather prominent, showing all the indications of a secondary origin. Isolated minute grains occur frequently within the feldspars, particularly the plagioclases. Vermicular quartz is conspicuous in many slides (sp. 5179, 5193), and seems to grade into the granular quartz already noted. One character which is noticeable in all the slides is the sharp outline of all the quartz areas against the discolored edges of the feldspars. Apatite in needlelike crystals is sparsely present.

As might be expected from the small proportion of the basic constituents to the whole mass, the rock is acidic. Specimen 5179 was analyzed by A. O. Dinsmore and W. P. Milliken in the laboratory of the University of Minnesota. It was selected as a representative sample of the granitoid type. It contains quartz and a mineral that acts optically like orthoclase feldspar, both in large proportions. A plagioclase of low extinction angle occurs in a few grains so altered that only in places could the twinning striæ be clearly made out. The alteration products are a kaolinic substance and vermicular quartz. The basic constituents appear in exceedingly small quantity. They are biotite and hornblende.

Mr. Otto K. Folin analyzed specimen 5723, which represents the more schistose portion of the rock at La Framboise's. Taken near the surface, it shows some discoloration, due to weathering, and doubtless a larger proportion of biotite is present. In field characters this specimen can not be separated from the granitoid phases with which it is in several places associated.

Analyses of granitoid gneisses.

Specimen 5179.		Specimen 5723.	
Constituent.	Per cent.	Constituent.	Per cent.
SiO_2	72.80	SiO_2	69.012
Al_2O_3	15.40	Al_2O_3	13.730
Fe_2O_3	3.10	Fe_2O_3	0.540
MgO	0.65	FeO	2.080
CaO	3.75	CaO	3.701
Na_2O	3.40	MgO	1.080
K_2O	....	Na_2O	4.196
H_2O	2.00	K_2O	2.330
		H_2O	0.130
Total	100.60	Total	96.799

The schist (sp. 5721) at Hindarmann's, less than a mile away, shows, as an average of two determinations, 70.56 per cent of silica. Mineralogically the rock is practically identical with specimen 5723. Specimen 5721 is the more altered. Both are much shattered.

GRANITE FALLS AREA.

Near Granite Falls are localities where rock similar to that at La Framboise's appears. Along the Great Northern Railway, recently built, some quarrying had been done. Extensive work was abandoned when it was found that the rock was so shattered that dimension stone could not be quarried. This is a typical gneiss so far as pertains to structure, although considerable variation can be seen. Inclusions of schist, some of them many feet in extent, are present.

The gneiss is, in general, a rock of medium color. It is strongly foliated by the alteration of quartz-feldspar bands with those consisting

largely of the bisilicate minerals. The quartz and feldspar present the usual characters of these minerals. The latter is represented by orthoclase, microcline, and a plagioclase of albitic extinction. The bisilicate constituents are muscovite, biotite, hornblende, and one or two pyroxenes. The muscovite is present in small folia scattered through a few altered feldspars, and none was seen that did not have that position. The biotite exhibited some folia of large size as compared with the coarseness of grain of the rock. In places a finely granular condition is conspicuous in thin sections. These areas are in such relation to the hornblende and pyroxene that their derivation from these minerals seems clear. The hornblende, while not abundant, is present in numerous places and always in association with the pyroxene. Nowhere, save in the schistose inclusions, was it seen in good-sized independent individuals, but rather as a fibrous uralitic variety, with indistinct optical reactions.

The pyroxene reacts like hypersthene; it shows the dichroism and usually the parallel extinction of this mineral. It does not occur in large individuals, as is the case in the gabbroid rocks of the valley, but the areas are segregations of numerous granules of varying size. Their edges are frequently fringed with the beginning of decomposition, as shown in the uralitic alteration product. The central portions of the segregations, as well as the individual grains, are rather fresh. Accessory minerals are few and of the same species as are met in nearly every gniessic exposure of the valley.

In the same areas in which the above-described augitic granite-gneiss occurs there is also present the normal hornblende-biotite-granite-gneiss. The color, texture, etc., as well as the petrological characters, are different, but there is no place where the field relationships can be seen, and thus a basis be formed for discussing their genetic relations.

AREA IN T. 114 N., R. 37 W.

A rock of special interest occurs in the "rock barrens" in secs. 7 and 8, T. 114 N., R. 37 W. It is a mass of rock quite different in outward aspects and internal structure and constitution from any of the gneisses which lie around it. It varies from them in color and texture, as well as in general habit, to a very marked degree. The color of the rock is reddish, except where augite or biotite predominates, when it becomes greenish or black, or where the feldspar becomes microcline, when a dirty white prevails. The texture is in places very coarse and pegmatitic, and again it is fine and sharply crystalline. Where the texture is coarsest some work has been done in a search for gold, but, so far as could be learned, entirely without success. In this work an excavation of several feet had been made (Ellingson's mine), in which a series of specimens was secured. Here were noted cleavage planes on some of the feldspars which were several inches across. Augite crystals were also broken out which, while in an imperfect condition, were more than an inch in diameter and of still greater length.

Beneath the road, just north of the south line of sec. 7, in the township cited, some blasting has been done. Here the rock has a medium texture, a bright, fresh color, and the feldspars are greatly in predominance. In general features this rock has every appearance of a gabbro. The color and habit of the feldspars, the presence of augite, the tendency in this mineral to alter into hornblende and biotite, the segregated condition of the mineral constituents, all tend to give a decidedly gabbroïd and nongneissic aspect to the rock.

The boundaries of this group of exposures are hard to follow, as the surface is to a great extent covered with grass. Everywhere that rocks were sampled at short distances from the above exposures they proved to be the ordinary red hornblende-biotite-gneiss or simply biotite-gneiss. It is clear, therefore, that this series of specimens (5372–5375, inclusive, and 5748–5754, inclusive) does not represent a rock variety of great extent or wide distribution. The only other place in the valley where similar features were seen was at Morton, where certain inclusions in the ordinary gneiss gave an appearance similar to this. Yet at Morton a gneissic arrangement of the mineral constituents is very pronounced, while here, on the rock barrens at the Ellingson location, the gneissic character is due partly to the direction of the feldspars in the ordinary texture of the rock.

There is nothing of note in the weathering of this rock variety. All its phenomena are identical, so far as observed, with those of the ordinary gneisses of southwestern Minnesota. Where the texture is coarse the corrosion or weathering has been greatly accelerated.

There are observed various gneissic phases from the granitoid to the well-defined gneissic alteration of bisilicate and feldspathic bands of mineral constituents. A strike of the banding N. 70° E. is seen, and the dip at Ellingson's mine is N., while in the road in sec. 7, T. 114 N., R. 37 W., the strike is NE.-SW., with a vertical dip. Some variation from the above strikes and dips was seen at other places.

In microscopical characters this rock is interesting. There is little quartz present, and what was seen gave every evidence of secondary origin. It occurs in the areas of pyroxenic alteration to amphibole and where biotite has been formed. There are also bands of quartz grains around the borders of the frayed-out feldspars in the altered portions of the rock. The feldspars themselves are largely microcline and partly a plagioclase of low extinction, regarded as anorthoclase or albite, with an occasional area of labradorite habit. In quantity the feldspar varies greatly, some hand specimens showing but a small proportion, while others are made up almost wholly of the feldspars and a few scattering grains of quartz. The pegmatitic samples show the feldspathic constituent to be chiefly microcline, which carries numerous intergrowths of albite and occasional inclusions of some variety of higher extinction well toward the anorthite end of the series.

The augite is green in color, weak in dichroism, and rather strongly cleaved. It possesses the physical characters of the ordinary variety

of the mineral. One crystal, more than an inch through, measured very nearly 87° and 93° on its prismatic angles. The usual extinction angle on prismatic cleavages was 39° to 43°. Alteration has begun in many places, and green hornblende is the first resultant product. Its first appearance was in small fresh areas in the midst of the augite individuals or in similar condition around their borders (sp. 5372, 5374, 5748, 5751), followed in later changes by well-defined individuals (sp. 5749, 5750) in which all the characters of common green hornblende are well displayed.

Biotite plays a somewhat important rôle in this series of specimens. It is found in large, well-marked folia, even in those sections where hornblende is just appearing along the edges of the augite individuals (sp. 5372, 5751). The relation of the biotite to the augite in such sections as were made of specimen 5748, where small areas of biotite lie in the midst of large augites, and its entire absence in other specimens where hornblende is strongly developed, give strong suggestion of its being a secondary mineral, and that its host is augite, and possibly in places hornblende also.

Sphene and epidote are both present in small quantities. The former is clear cut and wedge-shaped where the sections are in proper position. The favorite situation of the sphene is the circumference of the hornblende nests where associated with granules of quartz. It forms the boundary zone between these nests and the feldspars which make up the mass of the rock. Apatite is seen in the usual well-defined crystals, some of them attaining considerable size.

It is difficult to determine the relationship of this rock to the ordinary hornblende-biotite-gneisses around. Nowhere could the contact of the two be seen; yet the abrupt change in texture and mineral composition shows them to be widely different rocks. This augitic rock does not show evidence of being ordinary inclusions in the gneisses, like the masses which Mr. A. H. Elftman has found in the granites of northeastern Minnesota,[1] nor like those which the writer has seen around Rhinelander, Wisconsin.[2] Regarding the resemblances of the latter rock, Professor Van Hise noted these points:

> The microcline is very plentiful and the feldspars in extinction angles and species are the same as in the granites [of central Minnesota]. The areas of biotite, augite, and hornblende are large and numerous, the three minerals together composing more than one-half of the rock (sp. 5374). The biotite occurs in large brown flakes, exactly as in the hornblende-biotite-granites. As in these, the hornblende is secondary to the augite, but this specimen differs from any of them in the great relative abundance of augite, not more than one-fourth or one-fifth of this mineral having altered to hornblende. If this alteration from augite to hornblende had proceeded further and a portion of the feldspar had been replaced by quartz, this rock would have become a hornblende-biotite-granite.[3]

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[1] Preliminary report of field work during 1893 in northeastern Minnesota, by Arthur Hugo Elftman: 22d Ann. Rept. Geol. Nat. Hist. Survey Minnesota, 1894, p. 157.

[2] Geological excursion into central Wisconsin, by C. W. Hall: Bull. Minn. Acad. Nat. Sci., Vol. III, No. 2, 1891, p. 259.

[3] Van Hise, unpublished manuscript.

The foregoing very accurately expresses the conditions, and the writer's opinion is that here is a group of rocks which bears strong evidence of being a mass erupted under the same conditions, and possibly at the same time, as the great granite masses of central Minnesota, which have their typical development around St. Cloud, Sauk Rapids, and Watab.

HORNBLENDE-BIOTITE-GNEISSES.

With no perceptible change in the conditions and occurrence, the granite-gneisses of sec. 13, T. 112 N., R. 34 W., and the chlorite-gneisses of sec. 10, T. 112 N., R. 34 W., give place to the sharply contorted hornblendic biotite-gneisses of Morton and Beaver Falls. That the rocks around these two villages reach a considerable height above the present level of the river has already been pointed out in Chapter III. They stand nearly to the height of the prairies on both sides of the river valley. Indeed, this prominent position of the knobs of contorted gneiss can be seen in many places; a few miles above Redwood Falls, on the south side of the Minnesota; in the gorge of the Redwood River at and below Redwood Falls; on both sides of the Minnesota River around Vicksburg; at Minnesota Falls; at Granite Falls; and in the bottoms below Montevideo. The prairie exposures located on Pl. XV are all of this mineral type. The sharp contortion prevailing in certain localities locally obscures the strike and dip phenomena. In spite of this obscurity the general NE.-SW. trend of the pre-Cambrian formations across this portion of the State can not be doubted, nor can the series of crustal waves whose crests appear several times between New Ulm and Ortonville. In many places the hornblende-biotite-gneisses are very fresh. Elsewhere there is complete obliteration of all the normal characters of a gneissic rock, save perhaps in the lamination, through the complicated alteration process which the rocks have undergone. The two extremes of the series, the fresh and the completely altered, as well as every intermediate stage, can be seen where the Pacific division of the Minneapolis and St. Louis Railroad crosses the Minnesota Valley from the prairies of the north side to those of the south side of the river. This is along the south side of T. 113 N., Rs. 34 and 35 W. In the quarries and railway cuts at Morton occur some of the freshest exposures of the valley, or, for that matter, of the whole Northwest, and in the Birch Cooley Gorge, only 1½ miles away, can be seen equally fine and typical examples of the very extreme of alteration. Within a radius of 4 miles of Morton every intermediate phase of alteration can be seen. These phases have been considered in another place, and here only the mineral and physical characters of the normal gneiss will be discussed.

MORTON AREA.

In the quarries and railroad cut at Morton were found the exposures of freshest and apparently least-altered gneiss seen in this portion of the valley. *Fig. 5 (p. 28)* shows the contorted condition, with schistose

intrusions, and lenticular inclusions of coarser and scarcely laminated material. Pl. XVI, *B*, shows the mineral lamination of the rock as seen in the natural coarseness at the Morton quarries. The general color is dark gray, due to the light-pink hue of the feldspar and the large proportion of biotite. The arrangement and the thickness of the mineral bands vary considerably. Lenticular masses are frequent, composed largely of biotite, hornblende, and quartz. These are, as a rule, schistose and of medium grain. Less frequently the inclusions are decidedly hornblendic, actinolite being a prominent constituent. Individual areas within these inclusions shade off from green to white. They extinguish at angles of from 9° to 17° from the position parallel to the principal cleavage. Such actinolitic inclusions are not large, nor were they observed near the surface. It was in the deepest portions of the quarry that the specimens were taken (sp. 5737). Scarcely any mineral save hornblende is present in these lenses.

The coarser pegmatitic inclusions, consisting chiefly of orthoclase and microcline, are more frequent in some places than in others; for instance, at the railroad cut at the bank of the river they abound, while in the quarry some rods away they are rare. The bands of the normal foliated gneiss in places abut directly against these pegmatitic masses; again they wind around them and conform to their shape. Still elsewhere the bands fault and continue from a point some little distance, even 2 or 3 inches, away. The concretions of biotite are as uncertain and irregular in their distribution as are the pegmatitic masses. They are seldom over three-fourths of an inch across and carry rather large folia of biotite and a comparatively small proportion of other mineral constituents. The general direction of the laminæ immediately around Morton village is E.–W., bending to the south and north of this direction sufficiently to give a NE.–SW. trend to the formation of the area as a whole. The dip is, on the whole, northerly and varies from the horizontal to 50° and more.

The specimens gathered from the bottom of the Morton quarry and at as great a distance from the joints as it was possible to secure them show a less degree of alteration than do those taken from near the surface. The difference is not so much in the freshness of the constituent minerals as in the predominance among the latter of microcline and finely crystalline secondary quartz. As representatives of the freshest material, specimens 5734 and 5735 will serve. In these specimens the feldspars are orthoclase, microcline, and a plagioclase, in nearly equal proportions. The plagioclase is near the albite-oligoclase type, with its inconspicuous twinning and low extinction angles. The orthoclase and plagioclase seem to be more corroded about their borders than are the microclines. The result of this corrosion seems to be finely crystalline quartz, with a few minute, fresh microcline and orthoclase areas, which are brightly polarizing and free from inclusions. The larger, and perhaps primary, microcline areas contain less of the microcrystalline

accessories of decay and alteration—largely kaolinic material—than do the other feldspars named.

Biotite is the chief bisilicate mineral present. It occurs in isolated folia rather than in the segregated form seen in the gabbroid series of the valley. As a rule, the individuals are comparatively free from impurities, yet now and then a light-brown mineral of either clustered or reticulated distribution, thought to be rutile, is seen. This mineral is oftener, however, an impurity in the hornblendic constituent than in the biotite. Aside from these two, the rutile and the hornblendic mineral, accessories are unusually rare.

Specimens 5210, 5211, and 5212 show the condition of the rock at or near the surface. The proportion of secondary minerals is much greater and their individuals are much larger than the corresponding minerals in specimens 5734 and 5735. The orthoclase and plagioclase feldspars are considerably corroded. The microcline individuals are fresh and free from inclusions. Their size is greater than that of the other varieties of feldspar. They are rough and uneven on their borders, like the other feldspars. They contain inclusions of kaolinic material and small quantities of muscovite, as do the orthoclases, and in other ways they show evidences of alteration. Undulatory extinction is often seen. Biotite is the leading bisilicate constituent; indeed, it is practically the only one. The folia are small and sharply defined. As they lie beside each other they are bounded by even planes of contact. Inclusions are comparatively rare. The individuals are prone to segregate in clusters and bands. Not infrequently biotite inclusions occur in the feldspars, particularly the albite-oligoclase variety; indeed, they assume a fibrous condition, and appear between the twinning lamellæ.

Here and there a chloritic phase represents the bisilicate constituent, and rarely hornblende clusters are seen. The ordinary green variety of hornblende is the one present. It can not be determined that the deeper gneisses are of the usual hornblende-biotite type, although the analogy afforded by the valley as a whole gives strong reasons for such an assumption.

Pyrite is present in small quantities, and apatite is even more rarely seen. In addition to these two accessories, another is present, which at once attracts attention as thin sections are examined. It occurs in numerous circular areas, thickly studded with minute, dark, opaque spots. These circular areas are small, ranging between 0.075 and 0.250 mm. in diameter. Within them lie thickly clustered crystal granules of various shapes, together with an enormous number of black, opaque, spherical granules. The individuals are all so small that it is extremely difficult to determine the species present, but feldspar, hornblende, and biotite can be named with much assurance. A quantity finely pulverized and tested with the magnet gave a generous supply of black magnetic grains. When these circular areas were first noted, it was thought

that they must have been formed through the action of substances derived from the decomposition of iron-sulphide crystals and crystalline granules distributed plentifully throughout the rock. The granitic character of the rock would facilitate the spherical habit which these bodies invariably possess. The several processes involved in such an alteration might be followed with some positiveness were it possible to prove the mineral identity of the several species distinguished.

In chemical composition the rock as a whole shows a more basic character than the less foliated gneisses and granite-gneisses in other portions of the valley. This character will be seen by comparing the analysis below with the analysis of the Ortonville granite-gneiss, on page 63. A. D. Meeds, of the University of Minnesota, analyzed an average sample taken from the Morton quarry and reported as follows:

Analysis of the hornblende-biotite-gneiss of Morton, Minnesota.

Constituent.	Per cent.
SiO_2	63.61
Al_2O_3	16.71
Fe_2O_3	5.69
FeO	2.78
CaO	4.03
MgO	1.63
K_2O	2.49
Na_2O	1.68
H_2O	0.61
P_2O_5	0.25
Total	99.48

BEAVER FALLS AND REDWOOD FALLS AREAS.

At Beaver Falls the conditions are almost identical with those at Morton and along the Birch Cooley. At Redwood Falls also the same is true so far as the rock is in a fresh condition. The occurrence of altered gneisses shows essentially the same conditions and phenomena in all three of the localities; thus they are all conspicuous for the succession of changes easily traced from the fresh to the kaolinic condition.

The small exposure of gneiss in the woods between the road and the Minnesota River, along the bottoms between Beaver Creek and the Redwood Falls ferry, is worthy of notice. Specimen 5252 is from this locality. The knobs of rock extend in a direction N. 60° E. The largest mass of the group is only 175 feet long and 15 feet high. The prevailing color of the rock is red. While in general the appearance is that of a very fresh, firm gneiss, almost entirely unaffected by the kaolinization process which so conspicuously marks the gneissic exposures in the near vicinity, particularly along the banks of Beaver Creek, yet the entire mass is so shattered that not even a 3 by 4 inch hand specimen could anywhere be taken. The texture is medium, with

a slight tendency to porphyritic condition. It has a sharp angular fracture. The porphyritic condition disappears under the microscope. It is due to the cleavage of the scattered remnants of the feldspar individuals. Excepting these remnants, the entire mass is composed of secondary minerals. The quartz is entirely secondary and lies in minute, brightly polarizing, limpid areas. The few feldspar cores remaining are of the orthoclase and the anorthoclase-albite types. They are spherical or elliptical in shape, ragged, corroded on their margins, and somewhat altered within. The clustered and isolated secondary individuals are brightly polarizing, and represent microcline in large proportion, with scattering grains of andesine-labradorite.

The quantity of basic constituents is extremely small. No hornblende was seen. The biotite occurs in minute, sparsely scattered clusters of fibrous material, which generally disclose the radial extinction so frequently characteristic of chlorite. Magnetite is plentiful in minute, clustered, rounded granules, showing every evidence of secondary origin. Frequently around these clusters is red hematite. Some other accessories were noticed, particularly apatite, but they seem to cut no figure in the mineral composition of the rock, and are in all cases apparently the results of alteration processes.

The fractured condition of these exposures affords many narrow fissures disposed in every direction through the rock. Along the walls of these fissures can be seen numberless crystals of quartz and the several feldspars. In size they are small, rarely reaching a millimeter across. They proved too minute for microscopical determination, and too few were gathered to admit of a chemical analysis.

In all essential particulars these occurrences are identical with those noted down the river at La Framboise's farm, where the microcline crystals were 3 to 4 inches in size.

The altered gneisses mentioned as occurring around Beaver Falls and Morton (see pp. 29, 32, 59) show, in chemical composition, considerable variation from the fresh phases of the rock. The following analysis was made by A. D. Meeds:

Analysis of impure kaolin (sp. 5220) from Birch Cooley, Minnesota.

Constituent.	Per cent.
SiO_2	41.71
Al_2O_3	34.61
Fe_2O_3	4.58
FeO	6.88
CaO	1.16
MgO	0.22
Na_2O	0.11
K_2O	Trace.
H_2O	12.69
Total	101.96

CHAPTER V.

GABBRO-SCHISTS.

GENERAL CONSIDERATIONS.

Throughout the valley, intermingled with the normal acidic gneisses, are numerous occurrences of gabbro-schists, varying considerably both in mineral constituents and in chemical composition.

The salient microscopic characters of the gabbro-schists as a whole are the following: A dark-green to black color, due to the abundance of hornblende; a schistose structure, dependent in large degree on the parallel arrangement of the hornblende individuals; a freshness of appearance, due in part to the unweathered condition of the rock, and in part, no doubt, to the fact that the hornblendic constituent and some others are of a secondary origin.

Wherever these schists occur they exhibit a pronounced foliated structure, which in some places represents a gneissic rock and in others a schistose one. This difference seems to arise from the varying proportion of the feldspathic constituents on the one hand and the condition of the amphibole-pyroxene constituents on the other. Wherever the former predominate the amphibole-pyroxene minerals are segregated in bands, precisely as hornblende and biotite mark off the darker-colored laminæ in the normal gneisses, and where the feldspars diminish in quantity the rock becomes more and more homogeneous in constitution until a normal hornblende-augite-schist appears. This is the case in several localities, notably south of Odessa, in sec. 9, T. 120 N., R. 45 W., at several places around Minnesota Falls and Granite Falls, and in sec. 15, T. 112 N., R. 34 W. In dip and strike these rocks always appear conformable with the normal gneisses. While the normal gneisses display in places great contortion and diversity of direction, the gabbro-schist series, as these amphibole-pyroxene-bearing rocks may be called, are to a great extent free from that irregularity.

Structurally these rocks are subject to all the conditions of jointing, faulting, and vein carrying which obtain among the gneissic rocks. They are broken through by dikes and are apparently as little altered by the contact as are the gneissic rocks.

At several localities visited the gabbro-schists show no marked evidence of schistosity. Elsewhere, and generally, the foliated character is the most prominent feature of the rock. Thus the gabbro-schists appear massive in places at the "gold mine" in Minnesota Falls. A

MINERAL CONSTITUENTS OF THE GABBRO-SCHISTS.

The mineral constituents of the gabbro-schists are labradorite, pyroxene, both the orthorhombic and the monoclinic, with its alteration products, and hornblende, magnetite, and various accessory minerals—pyrite, apatite, titanic iron, garnet, and quartz.

The feldspathic constituent is the basic type, usually near to labradorite in its extinction angle and in its polysynthetic twinning. This last character is always present and distinctly visible, except when the sections are cut parallel to *b* (010), or in rare cases where alteration has obscured the lamination. In places the feldspars present some inclusions of foreign particles; but as a rule they are singularly free from impurities, save where these are the result of alteration. Such alteration products are chiefly kaolin and smaller quantities of epidote. The feldspars do not occur in lathlike forms. Were there no other means of distinguishing the rock from the dike bodies, this would prove an unerring one. The areas of this mineral show little difference in breadth and length.

Normal augite generally appears in thin sections. The exceptions are the hypersthene-gabbros soon to be described. It usually possesses the light-brown color characteristic of the rock-forming condition of this mineral, but in some places it varies to a pink, and only in polarized light can it be distinguished with certainty from the common garnet of the valley. Its cleavage is, as a rule, very distinct. Its alteration phenomena are of the usual kinds. Occasionally, however, the augite is badly altered to hornblende; in fact, hornblende has in places completely replaced its host.

Diallage, which Zirkel,[1] Rosenbusch,[2] von Lasaulx,[3] von Gümbel,[4] Naumann,[5] and others have regarded as an essential constituent, is always present in the Minnesota Valley gabbro-schists. It has in all cases undergone alteration, but the several stages of this change exhibit marked differences, described later, from those characterizing the hypersthene. In the diallage the alteration is to hornblende, but the process goes on in the middle of the crystal grains as well as along cleavages and fractures. A molecular change is seen. Pl. XIX, *A*, to some extent indicates this process. The fresh-looking diallage alters, molecule by molecule, to the dichroic green hornblende. In places the hornblende granules—or, as they more usually are, folia—have attained considerable size, while in other places they are so minute as to require an

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[1] Gabbro von der Westküste Afrikas, by O. Lenz: Verhandl. K.-k. geol. Reichsanstalt, Wien, 1878, Vol. II, p. 110: also Mikroskopische Beschaffenheit der Mineralien und Gesteine, by Dr. Ferdinand Zirkel, 1873, p. 441.

[2] Mikroskopische Physiographie der Mineralien und Gesteine, by H. Rosenbusch: Zweite Auflage, 1886, p. 132. Compare Microscopical Physiography of the Rock-Making Minerals, by H. Rosenbusch: Iddings's translation, New York, 1888, p. 239. "In the Archean rocks diallage is seldom met with. It is here confined * * * to certain amphibolites which may be considered as probably dynamometamorphic gabbros."

[3] Elemente der Petrographie, by Dr. A. von Lasaulx, Bonn, 1875, p. 310.

[4] Geologie von Bayern, by Dr. K. Wilhelm von Gümbel; Erster Theil, Grundzüge der Geologie, p. 129.

[5] *Lehrbuch der Geognosie*, by Dr. Carl Friederich Naumann, Vol. I, 1858, p. 573.

immersion lens to separate them from the diallagic matrix in which they are embedded.

The peculiar double cleavage of diallage is not seen on every granule of monoclinic pyroxene. Very likely many individuals, through the faintness of the secondary lines in the direction $\infty P \bar{\infty}$, may be regarded as the crystallographically intermediate forms between normal augite and typical diallage.

In a few places, as has already been anticipated, orthorhombic pyroxene, hypersthene, appears, but never to the exclusion of the monoclinic pyroxenes augite and diallage. In extent of alteration the hypersthene always takes precedence over all others. Rarely is an individual found without a strongly marked corrosion along its cleavages or the fractures which it carries. This alteration continues until the individuals are completely obliterated. The change is accompanied by the formation of areas of magnetite and fibers and broader bands of green hornblende. Other minerals result, but they are less in quantity and of minor mineralogical importance.

Both pyroxenes and feldspars are granular, neither seeming to play the part of matrix, but both being hypidiomorphic in their derivation and form. In the dike rocks, on the other hand, the augite is wedged in between the well-formed crystals of the feldspar constituent, or, in broad areas, it serves as a matrix in which the lathlike feldspar crystals have developed a very perfect form. Pl. XXV, *A* and *B*, show these differences very clearly.

The distinction here made between gabbros and diabases was first hinted at by Zirkel in 1866, when he described the labradorite of diabases as forming tabular crystalline individuals of distinct cleavage, varying color, and showing the characteristic twinning striæ of the basal face, while the labradorite of the gabbros exhibits distinct twinning striæ and occurs in coarse crystalline grains.[1] The pyroxenic constituent was, according to Zirkel, augite in diabase and diallage in gabbro.[2]

Magnetite, which is an almost universal constituent of the gabbro-schists, in places occurs in angular crystallized areas, seldom in single crystals but more commonly in rounded masses of very small size. It rarely shows traces of alteration into hematitic granules. That magnetite is a primary constituent of these rocks is by no means certain, so far as investigations now show. There is little doubt of its secondary nature where the hypersthene is altered; on the other hand, in northeastern Minnesota primary titaniferous magnetite in large masses occurs in the gabbros of Keweenawan age. It is probable

[1] Lehrbuch der Petrographie, Dr. Ferdinand Zirkel, Bonn, 1866, Vol. II, p. 78. "Der Labradorit bildet krystallinische tafelförmige Partieen von deutlicher Spaltbarkeit und weisser, graulichweisser oder grünlichweisser Farbe; sind die Krystalle noch frisch, so gelingt es oft die charakteristische Zwillingsstreifung auf der basischen Spaltungsflächen wahrzunehmen."

[2] Ibid, Vol. II, p. 110. "Der Labradorit ist glänzend weisslichgrau oder etwas ins bläulichviolette und besitzt in grobern krystallinischen Körnern deutliche Zwillingsstreifung."

that a portion of the opaque material which is visible in every slide is ilmenite or some closely related species, since titanic acid seems to be a common constituent of the gabbro-schists of Minnesota.

Accessory minerals occur everywhere in the schistose gabbros. The leading ones are pyrite, apatite, garnets, and quartz. Others appear as the modifying circumstances vary. Titanic iron, or menaccanite, doubtless occurs in small individuals in some specimens. Somewhat rarely the pyritic accessory has the golden-yellow color of chalcopyrite. The garnet and quartz are not contact minerals, as Teall seems to regard them,[1] but rather accessories and alteration products, to be found wherever alteration appears, whether brought about by weathering or by the deeper-seated change of metamorphism. The garnets are undoubtedly present in all contact alterations also, and perhaps have a still wider distribution than either weathering or deeper-seated alteration alone would produce. The quartz is regarded as partly an infiltration product and partly a by-product of the alteration of the augite to hornblende or biotite, or, as is often the case, to both.

Among the minerals which may be regarded as purely resultant products of decomposition, hornblende should certainly occupy the first place. Yet it is not safe to assume that all the hornblende is of this nature, for there is no sure means of determining the primary or the secondary origin of portions of this material. There is no doubt of the secondary development of by far the larger portion. It lies around the areas of pyroxene in such a manner as to preclude all doubt of its origin; it takes the place of pyroxene where such areas have become completely changed to a finely granular, bright-green, hornblendic segregation; and, finally, it shows a fibrous condition and a semigranular state within the feldspar areas, thus pointing to the breaking up of many individuals of this mineral. It may be said, in passing, that the parallel growth of augite and its resulting hornblende is very rarely seen; perhaps a half dozen sections were noted in the examination of these rocks which show this parallel position of host and product.

Passing to matters of more detail in the study of these gabbro-schists and to points which possess a somewhat local interest, we shall first describe the hypersthene-bearing gabbros; secondly, the hypersthene-free gabbros, and lastly the pyroxene-free gabbros or gabbro-diorites.

HYPERSTHENE-BEARING GABBRO-SCHISTS.

LA FRAMBOISE AREA.

A few paces from the river bank at the old La Framboise landing, in sec. 22, T. 111 N., R. 32 W., a mass of gabbro (sp. 5191, 5724) lies in the midst of the gneisses, constituting the large series of exposures in secs. 15, 16, 21, and 22 of this township. The relations of the gabbro

[1] British Petrography, by J. J. H. Teall, London, 1888, pp. 383, 385.

to the gneisses could not with certainty be made out, though, as will be seen later, the gabbro is probably intrusive in the gneisses. There is a sharp contact line where the two are seen side by side, which, however, can be followed a short distance only, owing to the covered condition of the rocks.

The gabbro here shows little of that schistose character almost everywhere present in the valley. The texture is medium, with perceptible tendency to porphyritic habit; to the unaided eye it is decidedly granular. The color in the mass is dark, a dark-green ground tone prevailing, with numerous white flecks which disclose the presence of feldspar, since they display, on some of the larger individuals, the polysynthetic twinning of the plagioclases. The dark-green grains show clearly the perfect cleavage of hornblende. The remaining constituents are not easily recognized with the unaided eye nor, in some cases, even with the microscope.

The rock is superficially weathered. The outer coating is of a reddish or dirty gray color, due to the alteration of the constituent minerals. When this coating—nowhere more than one-eighth to one-fourth of an inch thick—is removed, the rock is very fresh and sparkling. The green color just noted, and a tendency to crush to a light-gray powder under the hammer, suggest, however, that an alteration has really taken place and gone farther than the appearance of the rock would indicate. On account of the sharp contrast shown between this rock and the augite-gneiss in which it lies, and the general aspect which the rock carries of an eruptive species, the eruption of this mass into the gneiss can not well be doubted. The naked eye distinguishes a hypidiomorphic habit of the constituent minerals and the granitoid character of the gabbro rather than the ophitic or porphyritic character of a diabase.

The leading feldspars in this gabbro are near the labradorite-anorthite end of the plagioclase series. In shape the individuals are broad rather than lathlike. Twinning striæ are sharp and clear. The extinction angle on M is frequently 40° and more. Other areas cut on the pinacoidal plane give the extinction angle characteristic of mixtures with the formula $ab_1 an_8$ to $ab_1 an_{12}$; in other words, they extinguish around 30°. Undulous extinction occurs in a few individuals, particularly those cut in such direction that the twinning lamellæ do not appear, or if present are very far apart. This, therefore, is not a strong character of the rock.

In the several thin sections prepared there is little material which can be regarded as an alteration product from the feldspars. Now and then clusters of secondary grains and small crystals can be seen, but usually the inclusions within the feldspars are easily recognized as a pyroxene or hornblende. Microcline and plagioclases of low extinction, pointing to a high percentage of soda, were not noticed either as primary or secondary constituents.

The pyroxenes of this gabbro are two, and probably three, in number—hypersthene, diallage, and probably augite.

Hypersthene composes more than half of the bisilicate constituents of this gabbro. The characteristic dichroism of this mineral is sharply shown, as is also the parallel extinction of the grains. It is in the neighborhood of the hypersthene area that the grains and aggregates of hornblende are chiefly seen. Some of the hornblende individuals are isolated, and thus their genetic relationship to the hypersthene is obscured. It is possible that some individuals are not thus derived; yet the varying quantitative proportion of the mineral and the fact that its derivation from hypersthene can be clearly proved at other localities in the valley are the grounds for assuming such origin at this locality. There are no characters displayed by the hornblende so different from those at other exposures as to require further mention.

Diallage has suffered greatly through alteration. Grains have become diminished in size by the changing of their borders or interior portions, or both, into hornblende. The external characters of augite and diallage, save in one or two respects, are so similar that a sharp distinction between these two pyroxenes was not made. Where the characteristic cleavage of diallage was seen the identification of this mineral was considered sufficient. Many grains with a rather high extinction angle are entirely lacking in this character. The presence of augite is therefore assumed.

Pyrite is present in a few isolated and segregated grains.

WABASHA CREEK AREA.

Passing to the next district up the river from La Framboise's, we find, in sec. 15, T. 112 N., R. 34 W., a small exposure of hornblendic gabbro-schist (sp. 5399). Its lamination is not sharp and clear. Only a few paces to the north, and again a short distance to the south, stands a highly acidic gneiss in moderately high exposures, decidedly abrupt on the north side, and weathering in large, concentrically breaking blocks to a crumbling, dirty mass of feldspar chips. The direction of the schist exposure is NW.–SE., and the dip is apparently NE. at a medium angle.

In the gabbro-schist the individuals of feldspar vary greatly in size. Occasionally those of unusually large size are seen, but more frequently a finely granular condition prevails. The labradorite type abounds. A general freshness characterizes this mineral. Even where individuals are fractured and the joints have become filled with vein-like material there is no trace of decomposition along the margins. The twinning striæ are very strong. While this is true of most of the feldspars, there are individuals showing decided marks of disintegration. The product is a mass of finely crystalline, brightly polarizing, transparent material. Often in the altered individuals a fibrous radial arrangement of the decomposition product can be seen under crossed nicols. It is apparently a single mineral rather than a cluster of different species. This appearance leads to the opinion that the

process is a zeolitization of the feldspar rather than a saussuritization, since this process develops an aggregate of distinct minerals.[1]

The diallage is well marked with the usual characters of that mineral. In some individuals it has undergone alteration to hornblende to such an extent as to impart a green color to the residue of the decomposing grains. The double cleavage and the parting bands are not always distinctly seen; therefore some of the pyroxene may be assumed to be augite.[2]

Hypersthene occurs both in nests and in isolated grains. Where the latter appear they seem to have absolutely no crystal form; a decidedly granular condition is always present, and the ordinary prismatic cleavage is frequently indistinct. Where the hypersthene is segregated, several grains may lie side by side, having precisely the same plane of extinction and showing the same ragged and corroded outlines toward the feldspars as do the isolated individuals. Many hypersthene grains are completely altered into hornblende and some associated mineral, which may be ferrite; others are only partially altered. They carry within them small individuals exhibiting the cleavage and optic extinction of hornblende. Being considerably shattered, alteration first seizes the hypersthenes, producing along the cracks fibrous hornblende, which usually lies parallel with the cleavage striæ of the host. Around the borders of the changing hypersthene individuals, lying as though expelled by the alteration process from the midst of the hypersthene material and the resulting hornblende, is a granular mineral somewhat transparent and of light-brown color. Its minute size prevented further identification.

More rarely yet—as a rule, in the vicinity of these alterations—are larger masses of magnetite. Clusters and single grains exhibit the usual characters.

This locality further shows an interesting vein formation, evidently resulting from the joint action of crushing and mineral alteration. The mineral playing the leading rôle in the vein filling is hornblende. The anastomosing of the hornblendic material is marked, and is seen in Pl. XXIII, *A*. Crystal grains are broken, and between their fragments the minute leaves of hornblendic matter are seen, or grains are pressed apart and the interspace is packed full of the vein material. These veins were seen only in the much-altered gabbro-schists.

MINNESOTA FALLS AND GRANITE FALLS AREAS.

Around Minnesota Falls and Granite Falls there is a remarkable development of the hypersthene-bearing gabbros. One approaches a conspicuous belt of these rocks in ascending the river on the north side. The chief rock in secs. 11 and 14, T. 115 N., R. 39 W., is a gabbro. In the southeast corner of sec. 13 stands an area of well-banded gneiss

[1] Ueber Saussurit, by A. Cathrein: Zeitschr. für Kryst. und Min., Vol. VII, 1883, p. 248.
[2] British Petrography, by J. J. H. Teall, London, 1888, p. 132.

150 paces in extent which exhibits patches of coarse veinlike material. This gneiss is conspicuous for its small content of bisilicate constituents, its fresh microcline, and the undulatory extinction of its quartz areas. Along the boundary between secs. 11 and 14 and thence northward to the river are many patches of a black, distinctly laminated, hornblendic hypersthene-gabbro. The strike of these exposures is about N. 80° E. Along their southern border the dip is southerly, in sec. 12 reaching as high as 80°, while in the southern part of sec. 11 it is considerably less. Along the northern side of this section, while the strike is nearly the same as farther south, the dip is zero.

Throughout this whole area—and it embraces all the rock south of the great bend in the Minnesota River at Minnesota Falls, just below the site of the old dam and mill—granitic veins or dikes are numerous. In places, as along the section line between secs. 11 and 14, the granitic material is parallel with the lamination of the gabbros, and here and elsewhere the coarse texture of the former, as well as its sharp color contrasts, mark it as a phase of rock formation quite distinct from the latter.

Everywhere the lamination of the dark-colored hypersthene-bearing gabbro-schists is sharp and clear. The alteration to hornblende on the part of the pyroxenes has been carried so far as to give hornblende the leading place among the basic constituents, both macroscopically and microscopically. This altered condition of the rocks remains the same northward to the high, ragged, half-covered masses on the Russell farm, SE. ¼ sec. 11, T. 115 N., R. 39 W. On this farm the rocks have a northerly dip of 20° or more, with little contortion and with little special modification, even where they are broken through by dikes. This unaltered condition in the proximity of dikes can be well seen around the spot 1,300 paces N. and 1,800 paces W., sec. 12, T. 115 N., R. 39 W., where a dike (sp. 5280) 20 feet wide cuts through this same bed of gabbro-schist that first crops out on Russell's farm. Here and there a lighter color prevails, on account of the increase in the amount of feldspar, and in places through the light pea-green color of the secondary hornblende. A good illustration of these lithologic conditions is seen at the spot just indicated, near the contact of the dike. The gabbro-schist (sp. 5278, 5279) is hypersthene-bearing. Locally this bisilicate constituent almost wholly changes, leaving a rock largely composed of labradorite-anorthite feldspar and the alteration products biotite and hornblende (sp. 5279). Elsewhere the hypersthene and its alteration product, hornblende, are present in normal force. The rock then becomes a good example of a partially altered hypersthene-gabbro (sp. 5278, sl. 2237), and represents an intermediate stage of rock alteration. (See Pl. XXI, *A*.)

Crossing the river into Yellow Medicine County and into the ruined village of Minnesota Falls, one sees comparatively no change in the characters of the rocks. Near the old dam, swept away in the flood of

1882, which carried away the village itself, there are both a reddish, highly siliceous gneiss (sp. 5236, 5237) and a gabbro-schist (sp. 5238). The contact of the two rocks is here as clearly marked as at La Framboise's place, already described. The distinct interbedding, or at least interpenetration, of the two rocks is seen at the river bank at the south end of the old dam. Both the gneiss and the gabbro-schist are here more schistose than at La Framboise's, yet, barring certain modifications incidental to such schistose condition, they are the same in mineral composition.

The monoclinic pyroxene of the gabbro-schist has sometimes a greenish tint, and again it appears very transparent and free from color save the usual brown tinge seen in the thicker sections. It is now mostly of the diallage type, though frequently the foliation partings are indistinct or even wholly absent. The individuals are granular, never exhibiting crystal planes. Hypersthene seems rather more abundant at Minnesota Falls than at La Framboise's, and alteration has not crept into the internal structure of the grains with such marked effect. In both places the mineral is characterized by rounded grains instead of extended areas more or less interrupted by other minerals. Hornblende is the common product of the alteration of the pyroxenes. It is almost wholly in the compact condition, usually dark brown in color, and somewhat strongly pleochroic. The grains vary in size from the most minute, embedded in the hypersthene areas, to those as large as the pyroxene individuals themselves. Cleavage is perfectly developed and is always seen in cross sections of the prisms. Inclusions are rather plentiful.

A few hundred paces southwest of the ruined village of Minnesota Falls the gabbro-schists again appear, as in the western part of the village, in long extended masses, standing in billowy rows of knobs. From these exposures northward into and entirely through the city of Granite Falls to the banks of the river in sec. 13, T. 116 N., R. 40 W., these rocks can be followed by a succession of outcrops. The prevailing schistose character, the NE.-SW. strike, the dip alternating between NW. and SE., the dark color, the predominance of hornblende, and the generally fresh, undecomposed condition of the rocks very generally prevail. Near the center of the city of Granite Falls, one or two blocks north of the court-house, an interesting curve in the strata was noted, and to the west, near the house of E. C. Shannon, lies an exposure of a highly porphyritic modification of the gabbro (sp. 5438). This spot has already been mentioned (Chap. III, p. 35). The porphyritic character of the rock is shown in Pl. XXIV, *A*.

The texture of the groundmass is rather fine. Its color is a gray black. A certain granular habit is due to the shape of the pyroxenes, augite and hypersthene, and their relations to the feldspars and subordinate constituents of the rock. The numerous cleaved surfaces of the several minerals give a decidedly glistening appearance to the surfaces

of fresh fractures. A good pocket lens reveals on some of these surfaces the twinning lamellæ of plagioclase feldspars, and on others the strong markings of hornblende. Where the surface has been exposed for a long time it becomes a dull black color. The process of color change follows steadily the removal of the feldspars, the first step being contemporaneous with the incipient kaolinization of these individuals. The kaolinization process continues until the feldspar grains and crystals are completely altered and the soluble products are removed. Broken specimens show upon their fresh fractures every stage of the alteration process between the surface phase, where the feldspars are wholly removed, and that other extreme, only about one-fourth of an inch below the surface, where scarcely a trace of kaolinization can be seen.

Quite thickly studding this dark, medium-grained, foliated groundmass are the porphyritic feldspar crystals before mentioned. These crystals vary in size from a quarter of an inch to 3 inches in length, nearly all of them exceeding 1 inch (Pl. XXIV, *A*). Through the same kaolinization process characterizing the matrix the surfaces of these crystals exposed to the weather become white in color, dull in luster, and have been washed away until they lie in depressions below the general surface of the rock. Within they are of a greenish hue, owing to the presence of mineral accessories. Fresh surfaces show the perfect cleavage of feldspar, and when the cleavage is on a plane parallel with OP the striæ are very clear. These porphyritic feldspars are anorthite, as is seen from the extinction angle, 36°–43°, and the chemical composition given below. Besides the cleavage, there is a conspicuous fracturing of the crystals corresponding to the fractured condition of the matrix. There are many inclusions in these anorthite crystals. Among those identified are magnetite, easily separated from the powdered mineral, augite, which extinguishes at angles varying between 45° and 55°, and, in fewer numbers, slender, minute crystals of hornblende. The specific gravity of anorthite is 2.715.

Within the matrix the usual minerals of a hornblende-hypersthene-gabbro are seen, viz, labradorite-anorthite feldspars, hornblende, augite, diallage and hypersthene with the accessories, magnetite, hematite, and chlorite. The hypersthene has the usual pleochroism; it occurs in grains wholly devoid of crystal planes and usually completely enwrapped with the pyroxene and its decomposition product, hornblende. The pyroxene is only to a small extent diallage. This is indicated by the almost universal absence of the characteristic diallagic parting, as well as in the high extinction angle shown by the individual grains. Indeed, the prevalent prismatic cleavage and an extinction angle generally ranging between 42° and 48° point to augite as the predominant pyroxenic species.

The hornblende is well distributed. It is partly uralitic and partly in well-cleaved, brown individuals. There is little doubt of its secondary origin in both modifications.

The specific gravity of the matrix is 3.015.

The chemical composition of the porphyritic hornblendic hypersthene-gabbro is of interest. Analyses were made of both the matrix and the labradorite-anorthite crystals by Prof. E. J. Babcock, of the University of North Dakota. The following are his results:

Analyses of porphyritic hornblendic hypersthene-gabbro from Granite Falls.

Constituent.	I.	II.
	Per cent.	*Per cent.*
SiO_2 (silica)	47.43	46.40
Al_2O_3 (alumina)	23.66	33.87
Fe_2O_3 (ferric oxide)	13.06	0.34
CaO (lime)	11.21	14.73
MgO (magnesia)	3.15	0.04
K_2O (potash)	0.204	1.06
Na_2O (soda)	0.146	1.88
H_2O (water)	0.90	Trace.
Total	99.76	98.32

I. Porphyritic hornblendic hypersthene-gabbro (sp. 5438); the matrix rock, from which the anorthite crystals had been removed. Granite Falls.

II. Crystals of anorthite from the foregoing matrix.

From these results it is seen that the material agrees very closely in chemical composition with its physical characters as outlined on the preceding pages and determined by quite different methods. Attention may be called to the nearness in composition of the foregoing anorthite and that of the great gabbro masses of northeastern Minnesota, reported by Professor Irving,[1] and the Hammerfest (Norway) anorthite, quoted by Dana[2] from Pisani, first published in 1876.

Northwest of Granite Falls the gabbro lies in a gentle fold constituting the northern anticline of this locality. Along the south side of the river, from a little above the bridge and railway station, at present practically the middle of the city north and south, the road passes northwesterly in sight of almost continuous exposures of gabbro-schists for more than a mile. They are broken through in several places by the dikes which cross the valley in a NE.-SW. direction.

In this upper portion of the area the veins and feldspathic segregations are not so frequent as they are south of Minnesota Falls. Where they do appear they are a coarse mixture of green hornblende and labradorite or a closely related feldspar, with little, if any, quartz. The thin sections made show no appreciable quantity of this last-named mineral in the coarser segregations (sp. 5442). It is sufficient to say that they exhibit the lithological characters of the schists already noted lying along the south side of Granite Falls. The feld-

[1] The copper-bearing rocks of Lake Superior, by R. D. Irving: Mon. U. S. Geol. Survey, Vol. V, 1883, p. 438.

[2] A System of Mineralogy, by E. S. Dana, 6th ed., 1892, p. 339.

spar has the high extinction angle of anorthite. This mineral is little altered. Frequently the individuals carry minute crystals of pyroxene and hornblende.

The pyroxenic constituents are hypersthene and augite. The former is more generally altered than the latter. The hypersthene grains are frequently surrounded by borders of hornblende. It is probable that it is the source of the greater portion of the latter mineral. The monoclinic pyroxene has generally the green color already noted for other exposures in this neighborhood. Very rarely is the diallagic cleavage $\infty P \bar{\infty}$ (100) seen. Besides, the optical orientation determines the mineral to be augite rather than diallage, the extinction on the prismatic cleavage being between 47° and 50°. Hornblende is so abundant that the hand specimens were identified as hornblende-schist. The gabbroid character of the rock was not seen until the thin sections revealed the pyroxenic constituents.

On the north side of the river the gabbro-schists are finely developed at the bend of the river in Granite Falls, near the corner of secs. 33 and 34, T. 116 N., R. 39 W., and secs. 3 and 4, T. 116 N., R. 39 W., and thence northward to the Chicago, Milwaukee and St. Paul Railway station and the grain elevators of the city. Beyond these points gneissic rocks prevail to the northwest. They are of medium coarseness, distinct lamination, a prevailing dark color (which often, however, becomes somewhat lighter through the predominance of the feldspars), and a very fresh, vitreous surface along fractures. The strike of the laminæ is NE.-SW., with a dip of 37° SE. Several dikes break through these rocks. One, near the Pillsbury elevator, is of considerable width.

As will be seen in the list of literature references (pp. 12–19), these rocks have long been known to the geologists and explorers of the Northwest, yet their general external characters have been cited in the vaguest and most cursory way. Featherstonhaugh briefly describes[1] these exposures as "resembling granite in every particular except its stratification," and in a subsequent work[2] he mentions masses of quasi-stratified granite, most of which "were red quartzose granite with a slight quantity of mica, but some were gneissoid." N. H. Winchell says[3] that "At Granite Falls, as at Minnesota Falls, and all the way between, the rock in the valley is a schistose granite, almost a mica-schist, but it varies to a hard, gray granite that resembles that at St. Cloud both in color and composition." Upham[4] gives a much more precise description of the prevailing rocks, "the gneisses," as he designates them, of this locality.

[1] Report of a geological reconnoissance made in 1835, etc., by G. W. Featherstonhaugh: Doc. 333, printed by order of the Senate, Washington, 1836, p. 28.

[2] A Canoe Voyage up the Minnay Sotor, by G. W. Featherstonhaugh, 2 vols., Vol. I, London, 1847, pp. 333, 334.

[3] The geology of the Minnesota Valley, by N. H. Winchell, State geologist, and S. F. Peckham, State chemist: Second Ann. Rept. Geol. Nat. Hist. Survey Minnesota, 1873, p. 170.

[4] The geology of Yellow Medicine, Lyon, and Lincoln counties, by Warren Upham: Geol. Nat. Hist. *Survey Minnesota, Vol. I, 1884, pp. 596, 597.*

In microscopical characters they present a series from those exhibiting all the constituents in very fresh and apparently unchanged condition to those where many of the original constituents are completely obliterated through the metamorphic changes undergone. Such a series may be seen by comparing several of the accompanying illustrations. Pl. XVII, *B* (sp. 5335, sl. 2263), shows an unusually fresh hypersthene-gabbro taken from one of the small and somewhat isolated knobs southeast of Odessa. The feldspars are fresh and strongly polarizing, yet the pyroxenic constituent shows some traces of alteration. This specimen was taken to illustrate the freshest rock to be found at these exposures. Pl. XXI, *A*, shows (sp. 5278) a specimen taken south of the old dam in Minnesota Falls. The hypersthene at this locality is partly altered to a light-brown hornblende. The other constituent, a labradorite feldspar, is quite as fresh and unaltered as in the Odessa gabbro just mentioned. Magnetite is in the same physical condition and the same proportion in both. Again, in Pl. XXI, *B*, we see a gabbroid rock (sp. 5418), also from the southern part of Minnesota Falls, in which the pyroxenic constituents have entirely disappeared, having almost wholly altered into hornblende, with some addition to the amount of magnetite. The feldspars have also suffered corrosion to a very perceptible extent. The rock has thus become a diorite, a rock species which appears in several localities and in all cases under essentially the same physical conditions.

Everywhere about Granite Falls and Minnesota Falls the feldspar is sufficiently fresh to be identified, and with but two or three exceptions it is clear and brightly polarizing. The grains are of the typical hypidiomorphic structure. They contain few inclusions of any kind. The feldspar is of the labradorite type, but many variations from the normal extinction angle of this mineral were noted.

Augite, with its typical characters, is seen in almost every slide. Oftentimes areas occur which, both in general characters and in the more special ones, are hard to distinguish from diallage. In all the green color prevails, which has already been mentioned as characteristic of the pyroxenes in the gabbro-schists, while in the diabases of this same neighborhood the augite, where unaltered, is brown. In the matter of extinction, some areas present the normal angle of augite—45° and more in prismatic sections[1]—while others vary toward diallage. Diallage, with the typical characters, is also common. It presents some interesting illustrations of internal molecular changes, since almost everywhere in the valley the mineral is from circumference to center undergoing alteration into hornblende. A green color pervades the whole diallage individual, which some authors consider a mark of incipient alteration from diallage to hornblende, and here and there, in some cases thickly scattered through the host, are plates and fibers of

[1] Hülfstabellen zur Mikroskopischen Mineral-bestimmung in Gesteine, by H. Rosenbusch, Stuttgart, 1888, Tab. III, c.

dichroic hornblende. Rarely the diallage is fresh—that is, brown in color or slightly colored green; rarely, too, an area of clear hornblende appears which bears undoubted evidence of being derived entirely from a diallage individual; therefore, the great mass of material shows the intermediate condition above described, which is also illustrated in Pl. XIX, *A*.

Orthorhombic pyroxene appears in all stages of alteration, from the clear, fresh grains seen in specimens 5335 and 5445 (Pl. XVII, *B*) to the wholly altered pyroxene material lying in the long belt of knobs extending from the bend in the river, near the corner post of secs. 3 and 4, T. 115 N., R. 39 W., and secs. 33 and 34, T. 118 N., R. 39 W., westward along the north side of sec. 4, as well as northeastward through sec. 34. In the former specimens the fresh grains are strongly outlined against the plagioclastic feldspars, and exhibit scarcely any traces of decomposition, even along the cleavage lines. Other areas are partly altered (Pl. XXI, *A*), and still others are wholly altered (Pl. XXI, *B*). Thus the change can be clearly and undoubtedly traced. Much of the resultant mineral extinguishes parallel with that from which it springs, but occasionally it assumes a radial arrangement and lies in diverging fibers about the host. Hornblende is scattered everywhere through the whole series of slides examined. Many of the areas are brown and sharply marked off with cleavage lines, while others are green and ill defined. There is a strong dichroism in nearly all these individuals. In addition, many localities show a fibrous hornblende. This is always so associated with some pyroxenic mineral, usually hypersthene, as to give the strongest proof of derivation directly from it. Slide 9472 shows some areas of hypersthene fresh and almost unaltered, other areas partly altered to a fairly fibrous green hornblende, and still other areas, composed wholly of fibrous green hornblende, which bear evidence in their situation of having been formed at the expense of hypersthene individuals now totally obliterated.

Biotite, while occurring in many places in apparently independent areas, is noticed to be, as a rule, in such intimate association with the hornblende as only a descendant from that mineral can exhibit. Elsewhere it evidently springs directly from the alteration of the pyroxene. Rarely it is brown; as a rule it is green, and occasionally it is brown and green when rotated in polarized (not analyzed) light. Locally this mineral can be seen more frequently in sections from the Minnesota Falls samples than from those around Granite Falls. In some of those taken from near the road skirting the south side of the river to the north of Granite Falls no biotite whatever was seen. Much secondary hornblende is, however, present. Augite and hypersthene are both noted at these localities, and no doubt they both contributed to the formation of the hornblende.

Quartzite also occurs, but in every instance where seen it bears undoubted evidence of being a secondary mineral. The small, brightly

polarizing grains are free from inclusions. They occupy positions between the feldspars, even within them, and near the decomposing diallage areas. Also, wherever hornblende and biotite have been formed granules of quartz may be expected. The grains generally occur in clusters. Where quartz is present in isolated grains it is usually included in the other minerals.

Opaque minerals are frequent. Sometimes the areas can be proved to be pyrite, and at other times magnetite or a titaniferous magnetite must be assumed. It is common to see, microscopically, a partially or wholly altered pyroxene individual thickly strewn with spherical globules of some opaque mineral.

Apatite as an accessory is rare in all the Minnesota Falls and Granite Falls gabbro-schists; so, too, is sphene. Epidote occurs more frequently, seldom, however, in good-sized or well-formed individuals, but rather as a secondary product disseminated in small and clustered grains in the midst of other minerals, which thus play the part of host. It is thus found nestled in feldspars, in hornblendes, and in biotites.

MONTEVIDEO AREA.

Passing to Montevideo (see Pl. XI), we find a mound of the gabbroschist on the line between secs. 18 and 19, T. 117 N., R. 40 W. The mound stands 40 or 50 feet above the flood plain of the river, but its size is not great. The foliation of the rock is clear, with a NE.-SW. strike and a dip of 30° to 50° SE. The foliation is apparently due to the alternating preponderance of the feldspathic and ferromagnesian minerals. The feldspathic portions resist weathering longer than the basic, thus forming a corrugation upon the exposed surfaces. Numerous lenticular quartz veins occur scattered over the exposure. A slightly smoky appearance is noticed, as well as the skimmed-milk opalescence which was seen so markedly developed in the gneisses at La Framboise's, below old Fort Ridgely. The opalescence here is probably due to the same cause as at La Framboise's, namely, to needles of rutile scattered through the quartz grains, since these needles are seen in large numbers. Many cavities occur in the quartz, mostly gas filled. As a rule, they are arranged in planes passing through all the constituents of the rock alike, and suggesting conditions of origin similar to those pointed out by Julien in the gneiss of New Rochelle[1]. These quartz veins contain some feldspar, usually plagioclastic, and fibrous secondary hornblende. The gabbro-schist is medium to fine grained, gray in color, and somewhat weather stained. The feldspar is chiefly of the labradorite type. Some quartz is found. The proportion of basic constituents is unusually small. Some hornblende is present, as are also occasional folia of biotite. Both monoclinic and orthorhombic pyroxenes are present, showing the usual characters of these minerals as they appear elsewhere in the valley.

[1] On the fissure-inclusions in the fibrolitic gneiss of New Rochelle, by A. A. Julien: Am. Quart. Micros. Jour., Vol. I, 1878, p. 103.

Northwest of Montevideo, in the SW. ¼ sec. 31, T. 118 N., R. 40 W., stands a small exposure, only 60 paces in length, rising just above the level of the prairie. The strike at this exposure is N. 30° E., and the dip is 55° SE. On the northwest side the rock is a gneiss of a reddish-gray color, considerably altered, and highly siliceous, dipping beneath the gabbro, which constitutes the larger part of the rock in sight (see fig. 6, p. 37). The gabbro is a dark-colored, highly hornblendic rock, carrying lenses of coarsely crystalline hornblende. Its feldspar is of the labradorite-anorthite type. Quartz is extremely rare, as are also magnetite and biotite. The hornblende is so strongly individualized that it can not be regarded as secondary, yet analogy and the evidence of other localities in the valley and in Wisconsin,[1] as shown by the writer, all tend toward the view that it is secondary to pyroxenes. So long ago as 1882 Irving, basing his conclusions on the combined investigation of the rocks of Wisconsin by himself and Professor Van Hise, stated the conviction "that all of the hornblende of the rocks of this region is but altered augite."[2] Those words are of significance here, since the rocks of the two States are very similar in general characters, and at the time the report cited was published the schistose gabbros were for the most part classed as gneisses.

The pyroxene is in part monoclinic, doubtless three-fourths diallage. Its color is green, and there are evidences of alteration from the incipient stage to that where individuals are completely changed to other mineral species. The orthorhombic pyroxene, hypersthene, is like the same mineral in the many localities to the southeast, already described.

ODESSA AREA.

The last point up the river which discloses the presence of gabbro-schists is a moderate-sized exposure south of the Odessa station, on the Chicago, Milwaukee and St. Paul Railway, 1,200 paces N. and 1,500 paces W. of the southeast corner of sec. 9, T. 120 N., R. 45 W (sp. 5334, 5335). A knob some 20 feet in height and not more than 250 paces in length, largely turfed over, stands in the bottoms. The strike is N. 45° E. and the dip is 45° NW., although in places the schists seem to dip toward the southeast. The rock is dark colored, considerably weather stained at the surface, and very badly shattered. The texture is fine, for this type of rock, and the lamination is quite distinct. Both color and texture, aside from this character, are very even. Owing to the shattered condition of the rock, the effects of weathering extend rather deep. A rusted condition is seen along the sides of the fractures, penetrating the rock an inch or more. Where the fracturing is fine this condition induces a concentric weathering, which is conspicuous on the loose bowlders lying about on the outskirts of the quarry.

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[1] Notes of a geological excursion into central Wisconsin, by C. W. Hall: Bull. Minn. Acad. Nat. Sci., Vol. III, No. 2, 1891, pp. 256, 257.

[2] Crystalline rocks of the Wisconsin Valley, by R. D. Irving: Geol. Wisconsin, Vol. IV, 1882, p. 714.

Quarrying has disclosed the rock to a depth of several feet. From this depth the freshest specimens show an unusually fresh and unaltered condition of the rock. It is a typical hypersthene-gabbro-schist or norite-schist (sp. 5335, sl. 2263). (See Pl. XVII, *B*.)

It was from this quarry that a sample of an augite-schist was secured for the Educational Series of Rock Specimens of the United States Geological Survey (No. 140). The following is summarized from a description by W. S. Bayley: [1]

The rock is a very dark gray crystalline mass, with an obscure schistose structure and a sugary texture. Its grain is so fine that but one of its constitutents—biotite—may be recognized with any degree of certainty. This is uniformly scattered through the rock. In addition to this, there can also be detected a granular white mineral whose particles are so small that their nature can not be determined. The specific gravity of the rock is 2.770.

In thin section the rock is seen to consist chiefly of quartz, plagioclase, and pyroxene, with biotite, garnet, pyrite, and magnetite as accessory constituents. In natural light there appears an apparently homogeneous, colorless groundmass, in which lie large, irregular grains of a very highly refractive mineral with well-marked cleavage, smaller dark-brown flakes, small irregular or rounded grains or aggregates of grains of an opaque substance, and occasional isolated, highly refractive grains of a pinkish tinge. When examined with low power a certain parallelism may be detected in the arrangement of the various minerals. The majority of the brown flakes and of the highly refractive grains lie with their long axes in approximately the same direction. This supports the evidence of the unaided eye that the rock is schistose, and also the conclusion that the schistosity is not well marked.

When examined under crossed nicols the apparently homogeneous groundmass is seen to be an aggregate composed of very irregularly shaped interlocking grains of quartz and feldspar. Both are perfectly pellucid in natural light, and both contain the same kinds of inclusions. They may be distinguished by the brighter polarization colors of the quartz and by the twinning striations of the feldspar. From the intricate manner in which they interlock, it is impossible to determine which is the older. Both include small particles of all the other components, and therefore they must be younger than these. They contain also tiny liquid inclusions—a few with movable bubbles—large quantities of black, red, and green dust, and irregularly outlined green and reddish inclosures that appear to be either decomposition products of some substance whose nature can no longer be determined, or secondary infiltration products. The latter supposition seems the more plausible, on account of the varied character of the inclusions, which are at the same time undoubtedly such as are produced by secondary infiltration.

The feldspar, like the quartz, is in irregular grains, colorless, and

[1] See Bull. U. S. Geol. Survey No. 150, 1898, pp. 358–362.

pellucid. It is a plagioclase. The twinning striæ usually occur in a single series of parallel lines, but sometimes they appear in two series, crossing each other at nearly right angles. The maximum symmetrical extinction of two contiguous lamellæ, measured against their line of contact, is about 26°, indicating a plagioclase somewhere in the labradorite series. The specific gravity of the feldspar separated from the rock powder was 2.673. In any given position of the section between the nicols, one portion only of the lamellæ of any series of most grains is dark, the other ends of the lamellæ remaining bright. As the section is revolved the darker portions become bright, the dark zone gradually moving toward what were the bright ends in the first position of the section, thus showing fine undulatory extinction.

The irregular, highly refractive grains have a slight pleochroism in pale-greenish and pinkish tints, the latter when the most prominent cleavage runs perpendicular to the vibration plane of the lower nicol. The extinction is parallel to this cleavage where only one set of cleavage lines is observed, and on sections where two cleavages are seen it bisects the angle between them. The axis of elasticity parallel to the single cleavage is smaller than the one at right angles to it, and the double refraction is low. Since the long axes of nearly all the grains run about parallel to the plane of schistosity of the rock, and the sections are made parallel to this plane, it is not surprising that so few basal sections of the mineral can be found. In the one or two that may be discovered in each section there are two series of cleavage lines, which make with each other angles of about 88° and 92°. No inclined extinctions were seen in any section where only one set of cleavage lines appeared. The mineral is probably an orthorhombic pyroxene. It is usually fresh and free from inclusions. In sections cut from the weathered portions of the rock, however, an interesting alteration is observed to be in progress. The cleavage lines of the pyroxene are filled with a brown pleochroic substance without definite morphological characters. This brown substance gradually spreads into the surrounding pyroxenic material, replacing it in part, so that often what at one end is a perfectly fresh, almost colorless pyroxene is at the other end a mass of brown, pleochroic substance. As the amount of the brown substance increases its character becomes more pronounced, until finally the substance takes the form of biotite. The biotite often lies embedded in pyroxenic material, often it borders large grains of that material, and sometimes it occurs in the spaces between neighboring grains. There can be no doubt that it is an alteration product of the pyroxene.

The greater portion of the biotite in the section is in isolated grains between the colorless constituents quartz and plagioclase. Its long axes are nearly always approximately parallel to the long axes of the pyroxene. The mineral shows the ordinary pleochroism of mica. It is, of course, impossible to state positively that all of the biotite in the

rock has the same origin as that found in and near the pyroxene, but since it has exactly the same properties of the secondary mica we may say that it is probably of the same origin.[1]

The only constituents remaining to be described are garnet, pyrite, and magnetite. The first mentioned is in almost colorless, very highly refractive grains, without cleavages and without inclusions. They are irregular in cross section, but in outline approximate more or less closely to circles. They may be easily distinguished from all the other constituents, since they are perfectly isotropic between crossed nicols. The large grains are crossed by irregular fracture lines, distinguishable from cleavage cracks by their lack of parallelism. The garnets are found usually as inclusions in quartz. Reasons are given later (p. 102) for believing that the more abundant garnets of a gabbro-schist are of secondary origin. If this conclusion is true, it is highly probable that the garnet of this rock is also secondary, although the evidence is not so clear as in the case of the gabbro-schist referred to. The pyrite and magnetite both occur in irregular opaque grains that may be distinguished from one another by the brassy luster of the former in reflected light.

In an attempt to name the rock, we are met with the difficulty always experienced in discussing the classification of schistose rocks. No satisfactory method of classifying them has yet been proposed. It would seem best to confine the "schists" to aggregates of quartz and some bisilicate, and the "gneisses" to aggregates of quartz, orthoclase, and some bisilicate. According to these distinctions, our rock is neither a schist nor a gneiss, since it consists essentially of quartz, plagioclase, and pyroxene. It is a schistose rock with the composition of gabbro. Roth designates such rocks as zobtenites, and Dathe calls them flaser-gabbros. The flaser-gabbros, however, have a larger amount of hornblende; consequently our rock is excluded from that class. If we accept zobtenite as a general name covering all rocks produced from gabbros by pressure, it may safely be applied to the rock under discussion, for its composition is the same as that of the gabbros, and it has evidently been subjected to great pressure. Professor Hall, who has made a careful study of this rock in the field, thinks there can be no doubt that it was once a typical gabbro. If, however, we disregard the plagioclase as a classificatory element, we may call the rock a biotite-augite-schist.

In either case it is extremely interesting. Augite-schists are very rare, having been described only a few times in the literature of American petrography.[2] Zobtenite without hornblende, in which the pyroxene

[1] Preliminary description of the peridotytes, gabbros, diabases, and andesytes of Minnesota, by M. E. Wadsworth: Bull. Geol. Nat. Hist. Survey Minnesota, No. 2, 1887, p. 65.

[2] Microscopical observations of the iron-bearing (Huronian) rocks from the region south of Lake Superior, by Arthur Wichmann: Geol. Wisconsin, Vol. III, 1880, p. 645. Rocks of the Wisconsin Valley in the vicinity of Wausau, by R. D. Irving: ibid., Vol. IV, pp. 660 and 694-6. Preliminary paper on an investigation of the Archean formations of the Northwestern States, by R. D. Irving: Fifth Ann. Rept. U. S. Geol. Survey, 1885, p. 211.

and the plagioclase are perfectly fresh, are even more exceptional in occurrence than augite-schists, for the pressure that so squeezes a massive rock as to flatten its constituent grains produces a condition very favorable to the alteration of pyroxene into hornblende. Schistose gabbros, in which hornblende exists in large quantities, have been described in many foreign publications and in several in this country. It is not necessary to enumerate them here.[1]

HYPERSTHENE-FREE GABBRO-SCHISTS.

In several localities in the valley the gabbro-schists show no traces of hypersthene. In all other respects they are identical with the hypersthene-bearing masses just considered. Indeed, in several instances a series of samples was taken, one of which would exhibit well the characteristic hypersthene, while another, from the same belt and only a few feet away, would prove to be an ordinary nonhypersthene-bearing gabbro. At no place was there noted any geological change in general direction and situation, and the most careful examination failed to show any break whatever in the arrangement of the rock series. Further, the examination of samples in the study served to show no differences whatever between the several rocks, save the presence of hypersthene in one and the absence of it in another; every scale of proportion between these two extremes was seen.

At 800 paces N. and 400 paces W., sec. 34, T. 112 N., R. 33 W., there stands an exposure of a somewhat altered gabbro. It is a narrow belt, not more than 175 or 200 paces long, elevated only a few feet above the level of the flood plain of the river. Some contortion can be seen in the laminæ, but the general direction is NW.-SE. The laminæ stands about vertical. The rock is dark green in color, and under the hammer is extremely tough. Lighter-colored bands alternate with the darker and more basic. Pyrite is frequently seen in compact nests of crystals. A fine texture generally prevails.

Quartz has entered to no little extent into the mineral composition of this rock. It has assumed the pegmatoid character, and in many places affords a matrix to the other and older constituents, particularly to the kaolinized feldspars. Only occasionally is the feldspar sufficiently preserved to disclose its labradoritic character. The pyroxenic contents are augite and diallage in about equal proportions. The normal extinction of these two minerals is readily shown.

While it is more or less true of both pyroxenes, it is particularly so of the diallage, that it is in large areas and that the feldspars and other minerals occupy vermicular channels and spherical spaces within the diallage matrix. Pl. XXIII, *B* (from sp. 5199), shows a field of this kind in which feldspar, quartz, and hornblende lie in canals and open-

[1] The greenstone-schist areas of the Menominee and Marquette regions of Michigan, by G. H. Williams: Bull. U. S. Geol. Survey No. 62, 1890, pp. 52, 216.

ings in a single area of diallage. The boundary between the diallage and the included minerals is partly sharp and clear and partly broken up into narrow reaction rims, along which there seem to lie several minerals.

In the freshest specimens the augite and diallage are almost unaltered. In others they are both altered to hornblende. In places whole areas of these minerals are altered, and in other places rims of hornblende surround cores of the pyroxene. A decidedly fibrous character is in some places assumed by the secondary hornblende, and in other places numberless plates of green hornblende of minute size thickly stud the areas of pyroxene and give a green color to entire individuals. In the more weathered portions of the rock probably more than one-half of the bulk of the basic constituents is secondary hornblende, and there is in addition a considerable sprinkling of biotite. Between the folia of biotite are wedged many lenses of quartz and epidote. (See Pl. XX, *C*.)

Around Granite Falls several localities show no appreciable quantity of hypersthene in the gabbro-schists. South of Granite Falls, in sec. 4, T. 115 N., R. 39 W., lie some exposures of these rocks. While the great mass of the gabbro which stretches from this section northward, extending, with occasional interruptions, 2 or 3 miles, is hypersthene-bearing, several localities may be cited where no hypersthene whatever was seen.

In sec. 4, at 1,500 paces north of the southeast corner, some excavating has been done in a search for gold. The veinlike matter which has already been mentioned as occurring here was followed about 20 feet down. In the neighborhood of the vein the rock is decidedly massive, but at the distance of a few feet from the contact it has a distinctly schistose character. The pieces secured show admirably the shattering of the feldspars and the anastomosing through them of the veins of hornblendic material. A strongly marked diallage is the other leading constituent. No hypersthene was seen.

The rock at this locality shows some features of so much lithologic interest, particularly in the presence of a generous proportion of garnet (see Pl. XXII, *B*), that a set was collected for the United States Geological Survey's Educational Series of Rock Specimens (No. 109). Prof. W. S. Bayley prepared the description for this series, and from his description [1] the following summary is taken:

The prevailing color of the rock is dark green, speckled with large patches of dark red, and small areas of greenish yellow or white. Upon close inspection the yellow and white areas are seen to be the glistening cleavage surface of a striated plagioclase. The red areas are the surfaces of a dark-red, very hard, transparent mineral. It has no distinct cleavage, and is insoluble in acids. The properties are those of garnet. The nature of the dark-green matrix in which the

[1] See Bull. U. S. Geol. Survey No. 150, 1898, pp. 282-286.

garnet and plagioclase are embedded can not be determined, though from its dark color it may be assumed to be very basic. The specific gravity of the rock is 3.105.

Under the microscope the thin section shows a granular aggregate of plagioclase, green augite, garnet, and magnetite, with small quantities of green hornblende, a few grains of quartz, and tiny crystals of apatite.

The plagioclase is in irregular allotriomorphic grains, crossed by well-defined cleavage cracks and irregular fissures filled with decomposed products and stained by iron oxides. The feldspar is clear and colorless, except where rendered cloudy by inclusions. The most abundant of these are tiny flakes of chlorite and irregular masses of an opaque earthy substance, besides dustlike particles of magnetite and little nests of a brightly polarizing calcite. All these are usually abundant in the neighborhood of the fissures but are rare in the other parts of the grains. Other plentiful inclusions are long, narrow, apatite crystals with the ordinary characters. The average length of these apatite crystals is about 0.1 mm., and their thickness some 0.05 mm., though a few have cross sections measuring 0.2 mm. in diameter. Augite, hornblende, and large masses of magnetite are also included in the plagioclase, but these will be spoken of later.

Under crossed nicols the plagioclase twinning becomes very apparent as mediumly wide bands, usually running entirely across the grains. Some curve slightly, others wedge out as they pass toward the interiors of the grains, and still others spring from the sides of cracks, etc. These phenomena indicate that the rock has been subjected to pressure since it solidified. The schistosity observed in the field is probably a result of this. In certain restricted areas in the section, notably in the neighborhood of large garnets, there is often a second series of twinning lamellæ, with more or less undulous extinction, cutting the first series at some acute angle. The second series comprises numerous lamellæ, not so distinct as those of the first set and not so sharply marked off from one another. The specific gravity of the plagioclase is somewhere about 2.68, or near the andesine division in the plagioclase series, though probably a more basic member is also present, with a density of about 2.72.

The next most abundant component of the rock is a pyroxene, in green allotriomorphic grains and older than the plagioclase. This augite, where fresh, is marked by two series of cleavage lines, crossing each other at angles of about 90° in basal sections, and in other sections by a single series of parallel lines. The extinction is usually inclined to these. The augite in these sections may easily be distinguished from hornblende by the lack of strong pleochroism and by the large angles of extinction against the cleavage lines in a single direction, which often reach as high as 43°, whereas those of hornblende rarely approach 24°. Occasionally a slight difference in absorption may be detected in the mineral, but this is so slight that it may easily be overlooked.

In addition to the two cleavages mentioned as prominent in basal sections there is often another, presenting itself as a series of closely crowded parallel lines, bisecting the larger of the two nearly rectangular intersections of the cleavage lines. Since the shorter of the two lateral axes in pyroxene is the orthoaxis, this cleavage must be parallel either to the orthozone or to the orthopinacoid. It is determined to be an orthopinacoidal cleavage, which is characteristic of diallage. At one time this cleavage of diallage was regarded as original, and the mineral was considered as a distinct species of pyroxene. Now, as shown by Professor Judd,[1] it is known that the cleavage is secondary, and that its origin is often the direct consequence of pressure to which the rock containing it was subjected.[2]

Though much of the diallage is fresh, a still larger proportion is altered. The interior is often stained brown, or yellowish brown, and lacks the power of polarizing brilliantly. A little magnetite, in rounded grains, has formed around the edges of the altered portion, and a more or less fibrous cleavage has developed in it. In places the yellowish substance occurs in little plates or needles, arranged in parallel lines inclined to the cleavage, thus giving rise to the appearance of fine cleavage. In some cases the lines are so straight and narrow that they are with great difficulty distinguishable from true cleavage even under a high power. The origin of somewhat similar inclusions, so common a feature in diallage and hypersthene, has been the subject of much discussion, Judd considering them secondary infiltration products along planes of easy solution,[3] and others regarding them as original inclusions taken up by the mineral during its growth.[4]

Around the outside edges of the pyroxene another alteration is observed, it being surrounded by large plates or small granules of a bright-green substance with strong pleochroism in yellowish-brown and dark bluish-green tints and an extinction inclined to the cleavage. This substance, which is a hornblende, surrounds the pyroxene as a narrow rim, which sometimes extends into the pyroxene grain and at other times is formed of granules that seem to have been added to the grain after its formation. In either case the substance is to be regarded as secondary in origin.[5] In a few cases, where the pyroxene grains were small, the entire substance has changed, and in its place are now areas of hornblende that might be regarded as original were it not for the fact that so much of the hornblende of the rock is undoubtedly secondary. Another product, in some places formed by the alteration of pyroxene, is biotite. This is in small, reddish-brown flakes mingled with hornblende on the periphery of the areas.

[1] On the Tertiary and other peridotites of Scotland, by Prof. J. W. Judd: Quart. Jour. Geol. Soc. London, 1885, pp. 378–379.

[2] Preliminary description of the peridotytes, gabbros, diabases, and andesytes of Minnesota, by M. E. Wadsworth: Geol. Nat. Hist. Survey Minnesota, Bull. No. 2, 1887, p. 55 et seq.

[3] Loc. cit., p. 354.

[4] Discussions of the peridotites and norites of the Cortlandt series, by G. H. Williams: Am. Jour. Sci., 3d series, Vol. XXXI, Jan., 1886, p. 33, and Vol. XXXIII, Feb., 1887, p. 143.

[5] Note on the enlargement of hornblendes and augites in fragmental and eruptive rocks, by C. R. Van Hise: Am. Jour. Sci., 3d series, Vol. XXXIII, May, 1887, p. 385.

The magnetite and pyrite appear as large irregular grains scattered more frequently near the pyroxene and garnet than elsewhere in the rock. Both have resisted alteration and both are equally opaque.

The garnet is the characteristic mineral of the rock. It is in large, cellular masses, sometimes measuring a half inch in diameter. In the section it appears as a highly refractive, isotropic, deep-pink substance filled with inclusions and crossed by many irregular cracks, along the sides of which are stains of yellow iron oxides. So large and so numerous are the inclusions that the garnet substance, in its arrangement, reminds one of the section of a coarse sponge saturated with various colorless products. The largest and most striking of the inclusions are quartz grains. These are colorless and without cleavage traces. They inclose little mica plates, apatite crystals, dust particles, and thousands of small liquid-filled pores arranged in lines. Under crossed nicols most of the larger grains break up into aggregates, with the lines of inclusions passing from one grain into another without interruption. Occasionally some of the clear inclusions in the garnet are discovered to be plagioclase, but these are comparatively rare. The other substances inclosed by the garnet are small pieces of biotite, crystals and particles of magnetite, crystals of apatite, and thousands of tiny cavities filled with liquid. As in the quartz, these are arranged in lines, and the lines are sometimes continuous in both substances. This latter phenomenon would indicate that the inclusions are of secondary origin, and that they were formed after the quartz and garnet had assumed their present positions.

The associations of the garnet show it to be younger than the other constituents. Its cellular nature is evidence that it did not separate from the magma whose cooling gave rise to the main portion of the rock, because garnet formed in this way is usually among the oldest products, whereas in the present case the mineral is younger than even most of the quartz.

Another form in which the garnet exists is in small granules surrounding the magnetite. Here the mineral has the same properties as when in large pieces, except that it contains no large inclusions of quartz and feldspar.

The quartz is in colorless masses surrounded by garnet, as already mentioned, and also in larger pieces associated with the garnet but not included in it. It usually occurs most abundantly near the garnet, in the sections containing a great deal of that mineral, and is almost if not totally absent from the sections in which there is none.

Since the garnet is probably secondary, i. e., since it was probably formed after the main portion of the rock had solidified, it is probable that the quartz also is of secondary origin, and that the original components of the rock were essentially diallage and plagioclase, with magnetite, pyrite, and apatite as accessory constituents.

The rock is a gabbro. The principal mass under study is schistose, but it is evident that this is an imposed structure, since even in the

apparently massive variety represented by the hand specimen abundant indications of pressure are present. The massive phase, since it is characterized by the garnet, must be denominated garnetiferous gabbro. The schistose variety, being a squeezed gabbro, may be called a gabbro-schist.

Another rock, on the Russell farm, south of Minnesota Falls, possesses so much lithological interest that a set of specimens was selected to constitute one number of the Educational Series collected and distributed by the Survey (No. 144). The exact location is 800 paces N., 100 paces W., sec. 11, T. 155 N., R. 39 W. In the field, at this particular spot, the rock is distinctly foliated; it strikes nearly E.-W. and dips N. at 30°. The hand specimen at first shows little evidence of schistosity, but closer examination discloses the long axis of a majority of the grains lying approximately in the same direction, although not necessarily in the same plane. The following summary also is from the description prepared by W. S. Bayley.[1]

The rock is a medium-grained, distinctly crystalline aggregate of a white, striated plagioclase and a lustrous black hornblende showing a good cleavage. The cleavage surface is less even than that of mica.

The thin section of the rock reveals a general parallelism in the arrangement of its darker constituents. Most areas show only a coarse-grained aggregate of plagioclase and light-green hornblende. Other areas show in addition a very light-colored, highly refractive augite.

The plagioclase is in very irregular grains, clear and colorless except for tiny dustlike inclusions scattered through them. In addition to these it contains also tiny specks of magnetite and small flakes of green hornblende. Under crossed nicols the twinning lamellæ, in the majority of cases, form a single series of parallel lines. In other cases the lamellæ form two series, cutting each other at angles of about 78°. Some of the lamellæ run entirely across the grains, others spring from their edges and wedge out toward their centers, while still others spring from the sides of cleavage cracks and extend only a short distance into the feldspathic substance. In many grains the lamellæ have an undulatory extinction, different portions of the same lamella extinguishing in different positions of the stage as it is revolved. All these phenomena indicate that the feldspars have been subjected to pressure, which is probably the same as that producing foliation in the rock mass. The maximum symmetrical extinction of contiguous lamellæ is somewhere in the neighborhood of 33°, and the density of the mineral is 2.731. It is thus a basic bytownite.

Though the main mass of the feldspar is fresh, as has been said, the corners of grains and the small areas between neighboring ones are often filled with a micaceous, brightly polarizing substance, in tiny flakes, accumulating in little cloudy masses in and between the fresh plagioclase grains. The substance has the peculiarities of kaolin, a

[1] See Bull. U. S. Geol. Survey No. 150, 1898, pp. 369-372.

common alteration product of all feldspars, and is undoubtedly that material.

The hornblende is in large masses, of green color and of moderate pleochroism. Many of the grains have but one set of cleavage lines. The extinction against these lines varies between parallelism and an inclination of 28°, according as the section is parallel to the orthopinacoid or to the clinopinacoid, and the pleochroism is in clear-green and yellowish-green tints. Other grains have two series of cleavage lines. Where the lines are most distinct and most sharply cut, the angles made by the two series are 124° and 56°. The pleochroism is dark green and light greenish yellow; α=greenish yellow, β and γ=green. Absorption, $\beta=\gamma>\alpha$. The different individuals of the mineral are very irregular in shape, and usually four or five aggregate into groups. Most of these are simple individuals, but others have two or more parts in twinned relation to each other. The only inclusions noted in the hornblende were little grains of magnetite, small dust particles, and, in certain sections, masses of a light-colored, highly refractive mineral—augite.

This augite is found only in the interior of masses of green hornblende. It has a very high index of refraction, and is not pleochroic. It is either colorless or a very light shade of green. Under favorable conditions it may be seen to be crossed by two series of cleavage cracks making angles of nearly 90° with each other. The extinction bisects these angles, and the polarization colors are very brilliant. This augite is not always sharply separated from the surrounding hornblende. It gradually assumes a greenish tinge on its edges. This color deepens as the distance from the interior of the augite increases, and the substance acquires more or less pleochroism, until it finally becomes indistinguishable from the surrounding hornblende. This relation of the two minerals indicates that the hornblende has been derived from the augite.

Occasionally, in the edges of hornblende grains, and especially where these are in contact with feldspar, small, reddish-brown flakes of strongly pleochroic biotite may be found. These flakes sometimes extend, with frayed ends, far into the hornblende. Biotite is present in but small quantities, either between plagioclase and hornblende, as described, or between neighboring hornblende grains. It is probably secondary, being due to a reaction between the hornblendic and the plagioclastic materials. The alteration of hornblende into biotite is by no means unknown.[1]

The chief components of the rock as it at present exists are plagioclase and hornblende. The latter is evidently an alteration product of augite, and the plagioclase is bytownite. Both minerals are allotriomorphic, but the rock has been given a schistose structure by pressure.

[1] The greenstone-schist areas of the Menominee and Marquette regions of Michigan, by G. H. Williams: Bull. U. S. Geol. Survey No. 62, 1890, p. 182.

If we reconstruct the predecessor of the schist, we shall have a granular aggregate of plagioclase and augite—i. e., a gabbro. From the presence of hypersthene in the fresher rocks in the immediate neighborhood of this specimen, it is fair to presume that it was originally a hypersthene-gabbro. Its composition is now that of diorite, and its structure is schistose. Hence the rock may be termed a gabbro-diorite.[1]

Near Russell's farm, sec. 12, T. 115 N., R. 39 W., a sample was taken which lay almost alongside the gabbro just described—a typical representative of an altered gabbro. In this sample (sp. 5279) the pyroxene is almost completely altered to hornblende, yet enough remains to show the monoclinic habit of the constituent. The hornblende in this specimen exhibits in a very beautiful manner the characteristic granular condition which the secondary phase of this mineral assumes in nearly all localities and among all rock types of the Minnesota River Valley and of central Minnesota. Quartz is here an abundant accessory; so, too, is biotite in those areas within and around the space formerly occupied by the pyroxenes (Pl. XXII, *A*).

In the SW. ¼ of the SW. ¼ sec. 2, T. 113 N., R. 36 W., there stands a long, low belt of rather coarse hornblendic schist (sp. 5260, 5739, 5740, 5741). Everywhere over the surface course light-colored granitic veins. While these veins run in every conceivable direction, a general parallelism with the laminæ of the schist can be clearly traced. Their field relations to the ordinary gneisses can not be made out, further than that they lie near them, direct contact being thoroughly concealed.

The feldspars are well preserved in their general characters, few areas showing a breaking up into kaolin and here and there a staining by ferric oxide. Only a very few individuals of pyroxene are left from the alteration into dark-green hornblende, and these are green in color and augitic in optical characters. A few accessory minerals were also noted in the thin sections. So far as studied there seems to be little difference, in the degree of preservation shown by the individual minerals, between the finer, compact rock and the coarser, crumbling phases.

Save in the presence of augite at this locality there is almost no difference perceptible between this schist and that in sec. 4, T. 114 N., R. 37 W. (sp. 5376).

Three miles up the river from La Framboise's, in sec. 34, T. 112 N., R. 33 W., there stands a series of small knobs of a schistose rock, extremely tough under the hammer and almost unweathered. On macroscopic inspection there appears a contortion so marked that the true direction of the schistosity can not be accurately stated, but an average of measurements shows it to be nearly NW.-SE. The exposures stand about vertical. The contorted bands exhibit frequent nests of pyrite and many lenticular feldspathic streaks. The color of the rock is dark green, the texture fine.

[1] The gabbros and associated hornblende rocks occurring in the neighborhood of Baltimore, Md., by G. H. Williams: Bull. U. S. Geol. Survey No. 28, 1886, pp. 17, 27-32.

The three principal minerals present are a plagioclastic feldspar, augite, and magnetite. The feldspars are badly decomposed. Their alteration has proceeded so far that only occasional individuals are still sufficiently fresh to show the twin lamellæ. The two replacing minerals of the feldspathic constituent are kaolin and quartz, the last-named mineral appearing in very numerous but scattered granules.

While the feldspars are thus largely obliterated, the augite areas are unusually fresh. A green color predominates, and cleavage markings can be seen almost everywhere. The extinction angle is around 55°, thus indicating a normal augite. Not infrequently the individuals are of so large size that they include many other minerals, as feldspars and quartz. Some twinned forms occur. The hornblende, which for the most part seems to be secondary to the augite, is in small areas, either as narrow borders around the areas of augite or as small detached areas within the grains. In places biotite is present, and a characteristic of this mineral seems to be the intercalation of lenticular segregations of epidote and quartz between the folia. Either this is due to the alteration of some mineral which in its change produces both biotite and epidote, or the biotite has since its maturity yielded, as an alteration product, the material which has developed into the interfoliar epidote.

PYROXENE-FREE GABBRO-SCHISTS OR GABBRO-DIORITES.

In their alteration the gabbro-schists in several localities show a total disappearance of the pyroxenic constituent so characteristic of the fresher members of the series and its replacement by hornblende or by hornblende and biotite. In all their field relations—and they have been studied from one end of the valley to the other—no conditions of any sort were detected which might be regarded as peculiar to one member of the series and not to be found in another. The more or less schistose structure could be seen almost everywhere. The localities where this structure is lacking have already been indicated. The dark color, modified by the proportion of feldspar or the degree of hornblendization, was repeatedly seen. A medium texture always prevailed, frequently modified, however, by the occurrence of coarser segregations or laminæ.

While veins or dikes of a granitic character are abundant throughout the gneissic series, they are generally rare in the gabbro-schist.

In the west half of sec. 21, T. 114 N., R. 37 W. (Pl. VIII), there stands a mass of highly contorted hornblende-schist which is dioritic in type (sp. 5376). Some bands are biotitic. It is surrounded by several other knobs, at no great distance, which are gneissic. No well-defined direction of schistosity can be stated, yet the general strike is E.-W., with a northward dip.

Well-individualized hornblende occupies about two-thirds of the bulk of the rock. Frequently twinned individuals occur. The feldspar is

of the labradorite-anorthite type, and, while very fresh and strongly twinned, shows great unevenness in composition. In places a cloudiness, due to decomposition, completely hides the feldspathic characters, and in other places a ferric oxide is disseminated to a very considerable extent through the feldspars and hornblendes alike. Some rather large crystals of apatite were seen. This exposure seemed to be quite isolated from that of any other rock of similar type. Those which most resemble it are the dark-colored schists in sec. 2, T. 113 N., R. 36 W. (Pl. VIII), and in sec. 31, T. 118 N., R. 40 W. (Pl. XI), both of which have already been noted, the former still carrying some portion of pyroxene and the latter containing hypersthene.

Among the high, bold knobs of gneissic rocks which stand scattered throughout secs. 3, 4, 5, 10, and 11, T. 113 N., R. 36 W. (Pl. VI), are several interlaminated belts of hornblende-schist. In addition to these alternating bands, there are many lenticular nests, large and small. The texture is medium; as a rule, the broader, thicker bands are the coarser. The schistosity lies in a very regular direction, striking E. 10° S., and dipping southward from a low angle to one as high in places as 75°. In mineral composition this rock varies little from that just mentioned. The feldspars are more altered here than is the usual condition.

Coming again to Granite Falls and Minnesota Falls (Pl. X), several localities may be noted where the diorite-schists occur. In the south part of the village of Minnesota Falls, at 1,775 paces N. and 75 paces W., in sec. 11, T. 115 N., R. 39 W., is a finely crystalline schist (sp. 5418) which is badly shattered. It lies in the vicinity of a granitic vein of considerable size and only a short distance from a very prominent dike (sp. 5419). Examination indicates that this rock was originally a gabbro-schist, in which, at the present time, the pyroxenic constituents are completely obliterated. In spite of this fact the rock is fresh, and the existing mineral constituents can be diagnosed with ease. (See Pl. XXI, *B*.)

Starting southwestward from the corner post between secs. 33 and 34, T. 116 N., R. 39 W., and secs. 3 and 4, T. 115 N., R. 39 W., crossing the Minnesota River and proceeding a few degrees south of west for a mile or more through sec. 4, one passes a succession of knobs which have a schistosity striking westerly and dipping southerly. The prevailing color is dark, due to the predominance of hornblende. The texture is medium, and the whole aspect of the rock is bright and fresh. The mounds are not high; their linear arrangement and shape are due to the strike and inclination of the rock belt. There is little veining to be seen, and both structure and texture are very uniform throughout.

Still another locality is in the heart of Granite Falls, just north of the court-house and the several churches of the city. A belt of rather coarse gabbro-gneiss extends down from the northwest, swings round-

to the right, is interrupted by a narrow dike, and disappears toward the southwest. While the rock here is as fresh as along the belt just mentioned, it has a lighter color and a more gneissoid aspect, due to a smaller amount of hornblende. The term "gneissoid" is applied to indicate that the proportion of feldspar at this locality is much larger than in the typical exposures. Everywhere the feldspar individuals are fresh, brightly polarizing, and affected by alteration to a comparatively slight extent. Twinning is everywhere very pronounced, and the extinction angles point to the labradorite-anorthite type. The granular structure is very uniform, and all the feldspars are apparently of a single generation. Wherever alteration has crept in, it results in segregations of finely crystalline granules in the central portions of the individuals affected. Very little quartz was noticed, and that appeared to be secondary.

The leading basic constituent in all the specimens examined is hornblende. As a rule it is the green variety, but in one or two instances brown hornblende is present as the center or core around which the green is arranged. In a few instances a highly fibrous condition is seen, with a rim of deep green surrounding the areas packed with fibers. Since in this same group of rocks (sp. 5285, 5238, and especially 5445) the mineral hypersthene is seen changing into this fibrous hornblende, we can assume that origin for this portion of the hornblende. There is certainly every indication in the external and internal characters of these rocks to warrant such conclusion. If this view of the origin of the rocks carrying the fibrous hornblende be tenable, it must also be so of those in which this mineral is expanded into folia and grains, whether the folia and grains be green or brown in color. The same reasoning can be extended also to include masses in which a portion of the alteration product is chlorite and those in which a part of the hornblende has been further changed into biotite.

If lithologic proof of the character cited be insufficient to show the relationship of the hypersthene-bearing, the hypersthene-free, and the pyroxene-free rocks of this locality, the field relations may be cited. The belts of hypersthene-bearing rocks which occur in fine exposures in sec. 34, T. 116 N., R. 39 W. (Pl. X, sp. 5445, 5293), can be followed step by step across the river in a direction a little south of west, through sec. 4, T. 115 N., R. 39 W., until all the rocks of the valley finally disappear under the glacial drift which rises as the southwestern boundary of the river plain.

In the exposures north of the court-house, where the hornblende is scarce, the feldspars are apparently identical with those to the south in the long belt stretching from the neighborhood of the railway station entirely across the valley. But between the feldspar individuals there are bands and clusters of finely granular quartz. These lie, as a rule, along the sides of the feldspars which show most evidence of corrosion, and they bear every aspect of secondary origin. The hornblende

areas are usually clusters of individuals of small size lying compactly together, nearly all of them having substantially the same crystallographic orientation. They are undoubtedly secondary. The minerals adjacent to a dike are in no way different from the individuals of the same species lying many feet away. The rock is undoubtedly secondary to some phase of preexisting gabbro. It may have become somewhat more silicified than the other diorites and many of the gabbroschists of the valley during the metamorphism of the rocks.

On the top of the hill in the western part of the city of Granite Falls is a rock (sp. 5441) of rather peculiar mineral and textural composition. In only one other locality in the whole valley has such a rock been found, namely, at Montevideo. It is a somewhat porphyritic diorite. No augite is present, hornblende abounds, and biotite is plentiful. The hornblende is green and somewhat granular, with occasionally well-formed crystals extending into the old and partly kaolinized feldspars. The porphyritic feldspars are plagioclases, with the twinning striæ largely obliterated through the kaolinization. Around them is fresh, transparent feldspathic material, apparently orthoclase. The apatite needles, which are thickly strewn in every section, are of varying sizes and rarely entire. Many of them are not only broken and displaced, but are shoved until they overlap one another. (Pl. XXIV, *B.*) Aside from these minor characters the rock shows little effect of pressure.

CHAPTER VI.

PERIDOTITE AND SERPENTINE.

PERIDOTITE.

Peridotite occurs in only one definitely located spot in the Minnesota River Valley so far as is at present known. That spot is 1,300 paces N., 600 paces W., sec. 9, T. 112 N., R. 34 W., being 3 miles in a direct line southeast of Morton. As was stated in Chapter III, bowlders are found within a few miles of this place, in secs. 32 and 33, T. 112 N., R. 33 W., which are of essentially the same material.

The exposure in sec. 9 shows only a small area. The rock stands beside one of the many small lakes formed through the abandonment of a former channel by the river. Its entire length measures 300 paces, and a portion of this is now covered. There are no other outcrops of the crystalline rocks within a half mile, and in this exposure itself there is no visible evidence of other rock species than peridotite and its alteration product, an impure serpentine; therefore its relations to the nearest neighboring rocks, the chlorite-gneiss of sec. 10 and the ordinary hornblendic biotite-gneiss in the south half of sec. 4, could in no way be determined.

The present shape of these peridotite knobs is undoubtedly due to the erosion of the River Warren and its successor, the present Minnesota River. The strike of the knobs is N. 75° W., yet this can not be accepted as determining the direction of the eruptive material; it rather marks the direction of the currents of the eroding stream. Trees and turf cover the surface of the rock, save where the slopes are too steep to retain soil.

The rock is unusually dark colored. It exhibits many spots of a bronzelike hue, which are probably enstatite cleavages, and many dark olive-green markings of irregular contour. In more decomposed places the fresh fractures are spotted with bright green, pointing to the alteration of one or more of its constituents into chlorite. In still other places fresh fractures show that the color of the more massive portion varies to a mixture of dirty, light-brown patches set in a groundmass of dull-green, finely crystalline material, while at the surface the color becomes brown to black on account of the presence of organic matter. Beneath this superficial coating of foreign material the dull-brown color of the abundant limonite results from the proneness to alteration, one of the marked characters of the rock.

The exposures everywhere are badly fractured. Along every seam

and parting plane alteration has extended into the rock. Percolation channels are thus afforded, along which waters have corroded the rock, usually leaving a spongy, cavernous surface. Locally, however, there has been deposited from infiltration calcite in small masses, together with crystalline and crystallized quartz in much greater quantity. The quartz is occasionally amethystine, and clusters of rather small amethyst crystals were seen. The calcite was almost everywhere characterized by a waxy luster and by undulous cleavage planes.

In mineral composition the peridotite is varying. The freshest specimens are composed of enstatite and olivine, with their alteration products, serpentine, chlorite, limonite, and chromite. From this composition it is seen that the original rock was that variety of peridotite called by Wadsworth[1] saxonite, and described by Dathe[2] some years ago under the name enstatite-olivine rocks from Russdorf, Saxony. The rock of the Minnesota Valley differs from the type described by Dathe chiefly in the parallel (gneissic?) structure of the latter; both rocks are characterized by the predominance of enstatite over olivine and all other constituents, both accessory and secondary. The freshest specimens at hand (sp. 5215, 5731) show in several thin sections an average enstatite content near 40 per cent, while there is less than 10 per cent of olivine. Taking into consideration the secondary contents of the rock, and assuming their origin from their color and textural characters, the following estimate is made of the original mineral composition of this saxonite: Enstatite, 60 per cent; olivine, 35 per cent; all other constituents, 5 per cent; total, 100 per cent. The specific gravity of the rock, the average of four determinations, is 2.827.

Microscopically the enstatite grains are fresh in their central portions and disintegrated around their borders. Rarely are well-defined boundaries seen. Many areas are still large, indicating an originally coarse-grained rock. The color is light brown, the cleavage parallel to the axis *c* is conspicuous, and the separation of the grains is into thin plates, in many places so marked as to give a fibrous habit when the section is cut across the planes. There is no dichroism and the extinction is parallel. This is probably the oldest mineral in the rock.

Next in interest is olivine. This mineral is everywhere surrounded by secondary products. Its position indicates that it was formed subsequent to the enstatite. Many of the grains are included within the enstatite individuals, as Wadsworth showed for the Minnesota enstatite (hypersthene?)-bearing gabbros.[3] In every case there is between the two minerals a band of decomposition products partaking of the

[1] Lithological Studies; a Description and Classification of the Rocks of the Cordilleras, by M. E. Wadsworth, Cambridge, 1884, p. 125.

[2] Neues Jahrbuch für Mineralogie, Geologie und Palæontologie, by E. Dathe, Stuttgart, 1876, pp. 233–235.

[3] Preliminary description of the peridotytes, gabbros, and andesytes of Minnesota, by M. E. Wadsworth: Bull. Geol. Nat. Hist. Survey Minnesota, No. 2, 1887, pp. 59, 62.

nature of a reaction rim. Thus they are never seen in contact. This band resembles in color and textural characters the decomposition products of olivine, rather than of enstatite, as those products have been grouped in the examination of the thin sections. Owing to some local differentiation of which the rock seems to bear indications, olivine might originally have constituted the major portion within small areas, although it now comprises only a small per cent in the very freshest specimens. The grains are rounded and elliptical in shape. Generally several small areas lie clustered in the same crystallographic position, thus indicating that they are all parts of the same original crystal grain. Occasionally the existing grains are penetrated by veinlets of secondary material. This comparative freshness of certain grains may indicate, not any ability to resist decomposition, but rather that the prismatic zone of these individuals lies in the field.[1] The surfaces of the olivine grains generally show that rough appearance due to a high refraction index. Inclusions are rare, and the mineral is unusually free from impurities. This may be due in part to the fact that the portions of the several grains which were once studded with impurities were the first to succumb to alteration and have completely disappeared. (See Pl. XXVII, *A*.)

The remaining constituents of the rock seem to be secondary. The first among them in importance is serpentine. This mineral flows around the others as a matrix in which the remains of the primary constituents and the crystals of magnetite and other secondary minerals lie embedded. It constitutes nearly half of the entire rock mass in the freshest specimens, and an increasing percentage in the more decomposed, until the whole hand specimen is frequently serpentine. It is everywhere fibrous in structure. Locally it appears as plates across which the extinction shades play in wavelike succession as the field is rotated between crossed nicols.

An opaque mineral is present, which frequently presents the rectangular sections indicating cubic crystallization. In size the individuals seldom exceed 0.025 mm., although clusters are much larger. When crushed the rock affords a considerable quantity of a jet-black, strongly magnetic powder. Careful qualitative tests fail to give reactions for chromium or titanium. The mineral is therefore magnetite. These magnetite crystals occur in the most completely altered portions of the rock. Wherever there are traces of the enstatite or olivine the opaque constituent lies in clusters and dendrites of granular habit. These clusters are crowded to the walls of the percolation canals, and often afford boundaries between the primary constituents and the serpentine. So far as observed, magnetite does not occur within the unaltered primary minerals.

It has already been noted that quartz, in crystallized coatings and clusters of amethysts, is frequently seen along the joints and in the

[1] See Peridotite of Elliott County, Kentucky, by J. S. Diller: Bull. U. S. Geol. Survey No. 38, 1887, p. 12.

more-altered portions of the rock. Thin sections cut from the most-altered hand specimens show that quartz is steadily replacing the more soluble constituents. It occurs in finely crystalline aggregations as veins and tonguelike processes extending into the very interiors of the serpentinous areas. Locally it has replaced all other constituents. It is free from inclusions, and the grains are mutually penetrating. Some very beautiful specimens of vein quartz were seen in which the pyramids of opposite crystals interlocked and the concentric structure of the pyramids was a marked feature of the mineral.

Calcite is very seldom seen in the fresher hand specimens; in the more decomposed it occurs as incrustations of a resinous, yellowish-white mineral upon the surfaces of the joint planes, and microscopically within the rock mass as veins filling the spaces formed by the removal of the olivine material. It is probable that much of the carbonate is dolomite, since magnesia occurs so abundantly in both original constituents, enstatite and olivine, and the pulverized rock is more extensively dissolved in heated than in cold chlorhydric acid. It is in the partially altered rock that the carbonates are found; in those most completely changed quartz seems to be taking the place of all other minerals, both primary and derived.

Chlorite is present in small quantity in the more-altered portions. It presents the usual characters of this mineral developed as a secondary product in ultrabasic rocks, being fibrous in texture and sometimes arranged in rosettelike shapes of radiating needles.

Biotite is present in a few scattered folia, which were too minute for the complete demonstration of chemical or physical characters.

The chemical composition of the freshest specimens of saxonite (sp. 5215) was determined (I) by Mr. Alonzo D. Meeds, in the chemical laboratory of the University of Minnesota. A separate determination (II) of the silica and alumina was made by Mr. F. R. Smith.

Analyses of saxonite from the Minnesota River Valley.

Constituent.	I.	II.
	Per cent.	*Per cent.*
SiO_2 (silica)	43.65	43.52
Fe_2O_3 (ferric oxide)	15.94	....
FeO (ferrous oxide)	5.14	....
Al_2O_3 (alumina)	6.81	6.81
CaO (lime)	4.86	....
MgO (magnesia)	12.91	....
Na_2O (soda)	0.43	....
K_2O (potash)	0.52	....
CO_2 (carbon dioxide)	1.12	....
H_2O (water)	7.46	....
Total	98.84	....

I. Peridotite, var. saxonite. Sp. 5215. Locality, sec. 4, T. 112 N., R. 34 W.

II. Same specimen and same locality as I. A separate determination of the silica and alumina.

By comparison it is seen that the silica content of this saxonite is very near that of the olivine-enstatite rock (saxonite?) found on St. Pauls Rocks,[1] although in its total chemical characters it is close to the picrite of Schriesheim of Baden, analyzed by Fuchs.[2] The specific gravity of the two is very near that of Fuchs's Schillerfels, being 2.82.

SERPENTINE.

The serpentine is an alteration product of the peridotite, and as the alteration of the latter has already been considered, little need be said of the serpentine. It is, of course, the chief resultant product of the decomposition of the original minerals of the rock. Chlorite, magnetite, finely crystalline quartz, and one or more carbonates are also readily distinguished (sp. 5216, 5733). (See Pl. XXVII, *B*.) Serpentine varies considerably in color, the variation being due to the changing proportions of the accessory minerals. The dark-colored portions are the more compact and heavier. Calcite in unusually resinous habit is a frequent vein mineral in the serpentinous phases of this locality. The specific gravity of one of the bowlders collected in secs. 32 and 33, T. 112 N., R. 33 W., is 3.206.

[1] British Petrography, by J. J. H. Teall, London, 1888, p. 103.

[2] Schillerfels bei Schriesheim, by C. W. C. Fuchs: Neues Jahrbuch für Min., Geol., und Pet., Stuttgart, 1864, pp. 326–332.

CHAPTER VII.

DIKES.

OCCURRENCE.

From one end of the Minnesota Valley to the other dikes of a heavy, dark-colored basic rock—diabase—cut the gneisses and schists. These dikes, "the igneous filling of fissures,"[1] are usually in vertical position. Exceptionally they come to the surface by following the laminæ of the rocks through which they break, as at Montevideo. Every thickness, from a fraction of an inch to 165 or 175 feet, is shown. As a rule these rock bodies are nearly straight in their course, and they hold their thickness with surprising uniformity. It is extremely rare that one "pinches out" or that it is interrupted by the cutting across it of veins. Intrusions and veins of a granitic type are not here considered.

These dikes, with two or three exceptions, are of finer texture than the gneisses and gabbro-schists in which they occur. Structurally they are considerably shattered, and it is only in the broadest of them that blocks of any size free from joints can be seen. A basaltic structure is frequently evident, with the horizontal columns at right angles to the walls of the inclosing rock. Weathering has not yet attacked them to any marked extent, either on the exposed tops or where the country rock has been broken away on the edges of the dikes.

No products of disintegration are to be seen among the rocks, either in the shape of concentrically weathered blocks on the surface of masses or in comminuted rock débris in depressions. This is due in part, perhaps, to the comparatively recent removal of the loosened blocks, through glacial agencies, as fast as they became loosened in their places in the natural walls. It must be granted that a fraction only of the dikes actually occurring in the valley can be seen in the comparatively small area of rock surfaces in sight above the glacial drift and river alluvium. Those that were seen, and from nearly all of which specimens were taken, in the exploration of the valley are cited on the following page.

[1] Geology of Wisconsin, by T. C. Chamberlin, Vol. I, 1883, p. 43.

Dikes in Minnesota River Valley from which specimens were taken.

Location.	Strike.	Specimen number.
T. 111 N., R. 32 W., sec. 22	NE. and SW	5191, 5724
T. 112 N., R. 33 W., NE. ¼ SE. ¼, sec. 34	N. 60° E	5185, 5199
T. 112 N., R. 34 W., SE. ¼ NE. ¼, sec. 9	N. 75° W	5215–5216
T. 115 N., R. 39 W., SW. ¼ SW. ¼, sec. 1	N. 75° E	5238
T. 115 N., R. 39 W., SW¼ NW. ¼, sec. 12	N. 65° E	5280
T. 116 N., R. 39 W., SE. ¼ NE. ¼, sec. 29	N. 30° E	5286
T. 116 N., R. 39 W., SW. ¼ SW. ¼, sec. 34	N. 60° E	5294
T. 116 N., R. 39 W., NW. ¼ SE. ¼, sec. 34	N. 60° E	5295
T. 117 N., R. 40 W., NW. ¼ NE. ¼, sec. 34	N. 65° E	5299
T. 117 N., R. 40 W., NW. ¼ NE. ¼, sec. 34	N. 65° E	5300
T. 117 N., R. 40 W., SW. ¼ SW. ¼, sec. 21	NE.-SW	5303
T. 114 N., R. 38 W., NW. ¼ NE. ¼, sec. 13	N. 30° E	5368
T. 112 N., R. 34 W., NE. ¼ NW. ¼, sec. 24	N. 85° E	5403, 5763
T. 115 N., R. 39 W., NE. ¼ NE. ¼, sec. 24	N. 55° E	5419
T. 115 N., R. 39 W., NE. ¼ SE. ¼, sec. 4	N. 45° E	5423
T. 116 N., R. 39 W., NE. ¼ NE. ¼, sec. 32		
T. 116 N., R. 39 W., SE. ¼ NE. ¼, sec. 33		5432
T. 116 N., R. 39 W., NW. ¼ NW. ¼, sec. 33	N. 40° E	5440
T. 116 N., R. 39 W., NW. ¼ NW. ¼, sec. 33	N. 40° E	5441
T. 116 N., R. 39 W., SW. ¼ SW. ¼, sec. 34	N. 82° E	5442
T. 115 N., R. 39 W., NE. ¼ NE. ¼, sec. 4	N. 5° W	5443
T. 115 N., R. 39 W., NE. ¼ NW. ¼, sec. 4	N. 80° E	5446
T. 116 N., R. 39 W., NW. ¼ SE. ¼, sec. 34	N. 65° E	
T. 116 N., R. 39 W., NW. ¼ SE. ¼, sec. 34	N. 65° E	
T. 115 N., R. 39 W., NW. ¼ NW. ¼, sec. 3	N. 80° E	5769
T. 115 N., R. 39 W., NW. ¼ NW. ¼, sec. 3	N. 80° E	
T. 115 N., R. 39 W., NE. ¼ SW. ¼, sec. 4	N. 80° E	5446

The average direction of these dikes is as nearly NE.–SW. as can well be estimated, thus indicating the Lake Superior Basin as the point to the northeast toward which they, as a group, seem to trend. Between the valley and Lake Superior lies the great central Minnesota area of hornblende-biotite-granites, with smaller areas of gneisses and schists. Throughout this area, also, there are numerous dikes which, in many of their mineral and chemical characters and in their contact phenomena, are similar to those under consideration. In general direction, too, there is the same NE.–SW. trend in central Minnesota as was noted throughout the length of the Minnesota Valley.

The walls of the dikes present a sharp mineralogical contrast with the contact surfaces of the gneisses and gabbro-schists through which they break. Many slides were examined to discover whether any perceptible effect was produced by these intrusions of plastic basic matter on the containing rocks, but no very considerable effect was seen. The normal freshness of the gneisses and gabbro-schists is maintained throughout the entire zone of contact. There is a deposition of microcrystalline quartz along the immediate contact, and perhaps a slight kaolinization of the feldspars. Aside from the points noted, the gneisses and gabbro-schists were as greatly altered far away from any

known dikes as they were upon the very zone of contact. The two rocks, the dike and the country rock, are so firmly united that thin sections extending across the contact zone could frequently be made, as Pl. XXVI, *A*, will show (sp. 5294). Constant watch was kept, in passing these dikes, for some evidence of dynamic action suggested in their contact with other rocks and in their mineral structures. Nothing was seen that pointed to any profound disturbance subsequent to their intrusion. Nowhere was there seen any foliation of the rock itself or any development of foliated minerals, both of which, according to Williams,[1] are produced by dynamic action. Their position is always vertical, save where, as below Montevideo, they break through the gneisses along the lines of least resistance and thus follow, for short distances, the foliation of the rock. Nowhere was the foliated gabbro of such a diabasic type as to be regarded as a formation of similar origin with the contents of the dikes. Everywhere that a contact between the two was seen it proved the structural deformation of the former before the appearance of the latter.

From the foregoing considerations it will be seen that the lithological distinction between the gabbros and the diabases is as clear and undoubted as that between the gabbros and the gneisses.

Around Minnesota Falls and Granite Falls, as will be seen from the list on the preceding page, dikes are rather numerous. Many were seen which were not sampled and are not enumerated in the table. The general direction is NE.-SW. Their breadth varies from a few inches to 40 or 50 feet. They are all harder than the surrounding rocks, and resist weathering much better, and thus, in the low ground where erosion has been accomplished, these rock masses stand in ridges, either continuous or interrupted, which stretch for long distances across the valley and add in no small degree to the billowy aspect—due to unequal erosion of the rock masses—extending over several square miles in this neighborhood. All the dikes are much alike in color, in horizontal columnar structure, and in tendency to conchoidal fracture. There is a variation in texture connected with the breadth of the dike, and considerable difference in the degree of preservation of the original mineral constituents. In some of the dikes the basic constituents have been entirely obliterated, while in others alteration has obtained to only a slight degree.

AGE.

The nonlaminated character of all the dikes seen by the writer in Minnesota suggests that the crustal movements, local displacements, and foldings which were undoubtedly the chief agency in the formation of the schistose character of the other rocks of the region, took place long before the intrusion of the diabases. Another fact, already empha-

[1] The greenstone-schist areas of the Menominee and Marquette regions of Michigan, by G. H. Williams: Bull. U. S. Geol. Survey No. 62, 1890, p. 206.

sized, that no dikes have thus far been found among the horizontal sandstones and dolomites constituting the widely distributed Cambrian beds of the Northwestern States, places the period of their formation near the time of volcanic activity in the great Lake Superior syncline designated Keweenawan.

GENERAL PETROGRAPHICAL CHARACTERS.

Macroscopical.—These dikes vary in texture more than in structure or in chemical or mineralogical composition. This variation can often be seen as well in the central and marginal portions of the same dike as in two different dikes from extreme portions of the valley. As a rule, the narrow dikes are of firm, compact, and even texture, while the broader ones are correspondingly coarser and more porphyritic in habit. Everywhere the broken surface shows a firm, fresh rock, which rings under the hammer and separates with a conchoidal fracture into sharply angular fragments.

In color all the dikes around Minnesota Falls are dark, some of them almost black. Others take on a greenish hue, as, for instance, the great dike in the lower valley in secs. 23 and 24, T. 112 N., R. 34 W., which, according to the degree of alteration the rock has undergone, becomes in places of a decidedly pea-green color. Other dikes, as in western Granite Falls (sp. 5441), exhibit a color alteration toward brown. This is attained, however, by only a part of the constituents. In the field the darkness and evenness of color and the uniformity of texture enable one to distinguish at sight the dikes from the dark-colored laminated rocks through which they break.

The porphyritic habit of the broader dikes is very clearly shown to the unaided eye. The coarser-textured samples frequently exhibit cleaved surfaces of polysynthetically twinned feldspars from a half to three-quarters of an inch in length, and a general lathlike habit for all the individuals of these minerals. The fresher and more firmly textured dikes show in a less degree this same porphyritic habit.

Now and then are to be seen nests of feldspathic material due to the segregation of the feldspars. A greenish tinge is always seen in the midst of and around these segregations, produced by the alteration to hornblende of the augitic constituent in their immediate neighborhood.

It is true that many phases of texture and mineral composition can be seen. There is a wide range in textural characters. In mineral composition a variation has been traced as wide as the difference between an almost fresh and perfect condition of one of the essential minerals, augite, on the one extreme (Pl. XXV, *B*), and the utter destruction of this mineral and the building up on its remains of clear, fresh individuals of hornblende on the other (Pl. XXI, *B*). Yet there is no evidence at hand to show that these degrees of preservation are in any way due to a difference in the age of the dikes or

to any local conditions surrounding their intrusion.[1] The difference in mineral composition is probably due to unequal weathering. Nowhere in the valley has quarrying enabled one to gather evidence of any more deeply seated alteration.

Microscopical.—In thin section, as well as macroscopically, these dikes present the diabasic type. In places, as in the large dike south of Granite Falls (sp. 5423), a beautiful ophitic structure is seen. In some instances a porphyritic habit, with marked absence of the ophitic structure, is very pronounced. Pl. XXI shows very clearly the two types of diabasic structure exhibited by the rocks in the valley. Nowhere are these rocks entirely free from alteration, although some hand specimens freshly broken appear exceedingly fresh. The feldspars are assuming a more or less distinct kaolinization. The changes of the pyroxene to hornblende and biotite are as pronounced as in the gabbro-schists.

In its ordinary occurrence the feldspar appears in slender, lathlike individuals, either simply or polysynthetically twinned. They were developed very early in the crystallization of the dikes. Great diversity in the position of the individuals exists. Occasionally clusters of the feldspar individuals may be noted, which give to the naked eye the appearance mentioned as porphyritic. These clusters show at times a beautiful twinning of the crystals, as well as series of parallel-placed individuals. The twinning most frequently follows the Carlsbad law. The extinction varies somewhat, thus showing variation in the relations of the axis, as well as modifications in the chemical composition of the mineral constituent. As a rule the smaller feldspar individuals are rather free from inclusions, and in a majority of the specimens gathered even the larger ones contained few foreign bodies. Where inclusions do occur there are, in certain localities, abundant crystals and granules of hornblende gathered in the centers or cores of the larger feldspar areas. This segregation shows that a molecular change of no little importance and significance is going on among the crystalline constituents of these rocks. In other localities the feldspars are loaded with minute granules of a brown color. It is difficult to determine just what these inclusions are; in places they are granular, translucent, and, when taken alone, almost without color; elsewhere, when the granules are larger, they resemble minute particles of the ferric oxide, hematite, scattered through the field. In places the feldspars are partly altered into kaolin or saussurite. Occasionally the former seems to be the mineral formed by the alteration process, and again the latter, thus differing somewhat from the rocks of like nature in the Menominee region of Wisconsin and Michigan.[2] In a few cases microcline was observed to play a leading rôle. Aside from these

[1] Cf. M. E. Wadsworth: Proc. Boston Soc. Nat. Hist., Vol. XIX, p. 2; also Geol. Nat. Hist. Survey Minnesota, Bull. 2, 1887, p. 6.

[2] Consult further, The greenstone-schist area of the Menominee and Marquette regions of Michigan, by G. H. Williams: Bull. U. S. Geol. Survey No. 62, 1890, p. 188.

instances, where seen in subordinate quantity, its condition and environment are such as to lead to the opinion that it is a secondary product, as has been shown to be the case in the gneisses with which these dikes are associated.

The pyroxenic constituent is largely ordinary augite. Seldom, however, is this mineral fresh and unaltered save in the central portions of the areas. In the few instances where an unaltered grain is to be seen, a green or a pink color prevails in place of the ordinary light brown so characteristic of the mineral elsewhere. In places the individuals are large and constitute a matrix for the porphyritic lath-shaped feldspars, thus forming admirable examples of the ophitic structure. Where the proportion of augite to feldspar is small, the areas are minute and serve simply to fill up the interstices between the feldspar individuals. In the alteration of this mineral the change begins at the margin or along the numerous cracks which in the vicissitudes of time have been produced in the larger individuals. As a rule, hornblende is the direct result of the change, but more rarely biotite is one of the alteration products. In most cases the change, whether to hornblende or biotite, or to both, has introduced other minerals of secondary origin, the first of which is quartz in minute and clustered granules. Paramorphic hornblende is not produced by the alteration; neither is pseudomorphic hornblende a conspicuous feature of the change. To all appearances the resulting minerals encroach on the feldspars as well as on the pyroxenic constituents. Only rarely is the axial position of the original grains perpetuated in the secondary products—a phenomenon found in some instances in the associated gabbro-schists.

In the various stages of alteration from the rocks containing the clear and nearly fresh augite to those bearing fresh-looking green hornblende only, the whole cycle of changes from diabase to diorite is clearly illustrated. Only a step is lacking to show the evolution of the hornblende-schists. That step is the change brought about by mashing.

Quartz is found in nearly every dike. Nowhere was it seen as a porphyritic separation, as is the case in a few localities in Stearns County, Minnesota, but always as a secondary product accompanying the metamorphic changes in the rocks. The grains are very minute; they polarize brightly and are almost free from inclusions. In places they are clustered, suggesting miniature lenticular or gash veins of quartz. The vermicular quartz so abundant in all the gneissic rocks of this valley is usually absent in the dikes. In those samples where hornblende and biotite as alteration products occur in particularly large and pronounced individuals, quartz grains appear as a prominent portion of the intercrystalline material.

Accessory minerals, aside from those of a secondary origin, are comparatively obscure and unobtrusive. Both magnetite and pyrite are present, usually in rounded grains or clustered masses. Menaccanite

(ilmenite) also appears at times, surrounded by an encircling band of titanite. Occasionally numberless needles of apatite are to be seen.

The chemical constitution of the dikes has not been carefully studied. A determination of the silica in a specimen (5421) from Minnesota Falls showed 52.01 per cent. This is probably an average silica content of these basic rocks. It differs little from the silica content of similar dikes in central and northeastern Minnesota and northern Wisconsin and Michigan.

Passing to matters of detail and of a certain local interest, we note the following more special characters of the dikes already discussed in a general way.

MORTON DISTRICT.

In sec. 19, T. 112 N., R. 33 W., and secs. 23 and 24, T. 112 N., R. 34 W., lies a series of knobs stretching nearly east and west (see Pl. V). These knobs constitute a part of by far the largest dike seen in central and southwestern Minnesota. The width is from 165 to 175 feet, and the height of the knobs varies from 10 to 30 feet above the flood plain. The country rock is the hornblende-biotite-gneiss so characteristic of the Fort Ridgely district. So far as could be noted at the time of the visit, neither the texture nor the mineral composition of the gneiss was modified by contact with the intrusive. The dike stands vertical. Several cases of marked slickensides were noted where a readjustment had been effected between the dike and the gneiss. Texturally the dike is of medium grain, finer at the borders than toward the central portion, but occasionally carrying porphyritic feldspars. Little tendency to amygdaloidal structure was noted, and this near the contact of the gneiss.

The color of the rock is greenish black. The fracture is sharply conchoidal, and the rock rings under the hammer. Weathering corrodes it but slowly, the most perceptible result being a yellowing of the surface through the change of the iron pyrites to a hydrous ferric oxide.

In mineral composition this rock is a partially altered diabase or diabase-porphyrite. The feldspar is plagioclastic, lying in lathlike forms. The porphyritic areas resolve into more or less altered segregations of the lathlike forms instead of exposing broad, polysynthetically twinned plagioclases, as in the gabbro-schists. The individuals are comparatively free from primary impurities, but kaolinization has crept in to a considerable extent in some cases. The segregations mentioned decompose into a fibrous mineral of a slightly green color, with parallel extinction, probably saussuritic in composition.

The augite is more or less altered, and everywhere lies between the lathlike feldspar individuals. Where fresh a light-brown color prevails. The angle *c* varies from 37° to 43°. Alteration has nearly everywhere set in, resulting, first, in green hornblende, partly massive and partly fibrous, and, second, in biotite. The process has not proceeded far enough to give distinct and individualized forms to the resultant

minerals, except near the surface, where the alteration has gone so far as almost to obliterate the augite individuals.

Magnetite and pyrite occur in grains of varying size and shape, not as a rule of great size nor of any regularity of form. Skeletonlike aggregations of pyrite are sometimes very noticeable. Epidote and apatite are both disclosed by an inspection of thin sections. The latter is present in some portions of the dike in numerous long, slender, needle-shaped crystals, frequently broken.

Quartz as a resultant of the alteration processes rather frequently appears in brightly polarizing areas. As a rule these areas are not large, and they lie in the most-altered portions of the rock. Surface weathering is especially effective in developing this mineral, which is deposited in the contact areas between the inclusions and the normal rock. It extends into both portions, filling interstices in the diabase as well as forming the outer zones of the inclusions themselves, and by degrees gives place in the feldspars to the kaolinic alteration product. In these situations the quartz throughout large masses of the rock has arranged itself in the same crystallographic directions, thus extinguishing simultaneously in large areas, even though, as appears in the section, the different portions of quartz be entirely separated by other minerals. Pl. XXVI, *B*, is an effort to show this intercalated quartz as it is exhibited in specimen 5400.

VICKSBURG DISTRICT.

In the Vicksburg district (see Pl. VIII), in the area designated "rock barrens" by the land surveyors, there are several dikes. One of them, in places 40 feet wide and having a direction N. 30° E., lies exposed at several points in secs. 12 and 13, T. 114 N., R. 38 W. The color is a mixture of green and white. Weathering has changed the surface to a dull, dirty brown or reddish brown. This dike is of medium coarseness. The texture is distinctly diabasic. This and the narrower neighboring dikes are considerably shattered.

The leading mineral constituents are a plagioclase feldspar and one or two pyroxenes. At the surface the feldspar is so greatly altered that the extinction angle can be read in only a portion of the individuals. This extinction points to the anorthite end of the feldspar series. The usual twinning phenomena were noted. The product resulting from the alteration of the feldspar seems to be kaolin. The pyroxene is so completely altered to hornblende that the optical characters of this constituent could not be well determined; 39° marked the extinction of one small core, which placed that individual in the category of ordinary augite. Green hornblende is the leading product resulting from the breaking up of the pyroxene. It is in places developed into well-formed individuals, some of which are strongly twinned. In places the hornblende individuals, as well-developed plates, lie in a matrix of clear secondary quartz, and again a decidedly fibrous condi-

tion prevails, and quartz may or may not be present. A few small areas of biotite seem to spring from the alteration of the hornblende. Quartz is scattered throughout the rock as interstitial matter, generally taking the place of the feldspars. Occasional small areas are pegmatitic. Magnetite is present in small, scattered grains and crystals. Apatite needles are rather numerous, although small.

GRANITE FALLS DISTRICT.

In the Granite Falls district (Pl. X) there are a large number of dikes. Among them are those which are ophitic and very fresh, and others which have lost all their pyroxenic constituents through alteration into hornblende. These last are simply diorite dikes. No geographical classification is possible, since the degree of alteration seems to depend in large measure on the width of the dike and the conditions of rock association under which it occurs.

The two dikes which represent most perfectly the ophitic structure lie the one on the north side of Granite Falls (sp. 5286), 1,100 paces N., 100 paces W., sec. 29, T. 116 N., R. 39 W., and the other to the south of Granite Falls (sp. 5423), 1,000 paces N., —— paces W., sec. 4, T. 115 N., R. 39 W. The former has a width of 40 feet and a course N. 30° E. The latter is at least 25 feet wide and runs N. 45° E. While the texture of these two dikes is medium it is coarser than that of others in this district. The color is dark green to black. On the borders of the dikes there are traces of an amygdaloidal structure in the occurrence of vesicles. Rarely porphyritic crystals of plagioclastic feldspar are found. The augite occurs in large areas from 2 to 5 mm. across (see Pl. XXV, *B*, from sp. 5286, sl. 2241). Their borders are somewhat roughened by alteration and the intrusion of secondary hornblende. Freshly fractured surfaces of the rock show numerous cleavage planes of the augite thickly interwoven with the cleaved lathlike crystals of the feldspar. The spaces between these augite surfaces are filled with a finely granular matrix, which lacks the bright reflection just mentioned and is of a green color. These reflecting surfaces seem to be identical with those described by R. Pumpelly in the melaphyr or "greenstone" extending along Keweenaw Point and stretching southwestward.[1] The structure has been seen by the writer in many rocks of the Northwest, including diabases, gabbros, and even granites. Aside from the lathlike labradorite crystals which penetrate them in every direction, the augite crystal areas are singularly free from inclusions. There are fractures which to a greater or less extent serve as alteration zones and facilitate the progress of mineral changes.

The feldspar crystals, which are labradorite or very near it in optical characters, are filled with brown, dustlike inclusions. Their distribution through the feldspar crystal is not uniform, but they are

[1] Metasomatic development of the copper-bearing rocks of Lake Superior, by R. Pumpelly. Proc. Am. Acad. Arts Sci., Vol. XIII, 1878, pp. 260-261; also Geol. of Wisconsin, Vol. III, 1880, p. 33.

clustered in certain portions, where they impart a decided brown color to the mineral. Another inclusion which seems to be quite common in the feldspars is finely granular augite, which was apparently caught up in the crystallization of the rock. The boundaries of the feldspars are sharp and smooth planes. The shreds and prismatic blocks of augite everywhere seem to penetrate them. This is more particularly true of the ends and diagonal edges of the feldspars than of their prismatic surfaces.

Olivine is present, but only a few central cores remain of what was once no inconsiderable constituent. The rough surface, bright polarization colors, and optical extinction show the nature of these cores. They are bounded by a bright-green hornblendic alteration product which is radially developed around the cores. Associated with the hornblendic product is a black, opaque, granular material, probably an oxide of iron, which in places is developed in æstivated forms, due to the contact of the granules. Magnetite in large crystals and granular areas is a comparatively frequent mineral. Biotite was seen in all the slides examined, doubtless occurring as a secondary product.

Entering the neighborhood of Minnesota Falls and Granite Falls from the south, one meets the first dike to the south of Minnesota Falls, in sec. 12, T. 115 N., R. 39 W. This dike (sp. 5280), about 20 feet in width, breaks vertically through a gabbro-schist. The feldspars were lath-shaped individuals; the original boundaries of many are now obliterated, and the polysynthetic twinning can no longer be seen. Nowhere is augite visible, but its place has been taken by hornblende and biotite as secondary products. The hornblende occurs in fine granules, lying sometimes in parallel position, but usually scattered in all directions. The proofs of the secondary nature of the hornblende do not lie in these slides only; they can be seen in the rocks of the locality taken as a whole. At this place the gabbro-schist cut contains much fresh pyroxene, and yet this mineral has utterly disappeared in an intersecting dike. Magnetite, epidote, and pyrite are present. The last two, and doubtless much of the first named, are secondary minerals.

Just across the river, in secs. 2 and 11, and almost due north from the dike just described, extend other dikes, somewhat broader and coarser textured (sp. 5419). The direction is N. 44° E. Mineralogically they are almost precisely like the dike south of the river (sp. 5280), differing chiefly in their coarser texture, in the larger proportion of secondary biotite, and in the skeletonlike segregations of pyrite. The alteration of the pyroxene into hornblende has proceeded far enough to change to some extent the sharp boundaries between the feldspar individuals and their basic neighbors.

In sec. 34, T. 116 N., R. 39 W., East Granite Falls, around the railway station and the grain elevators, and stretching southwestward to the

river, are several occurrences of dikes. One of them appears to be of considerable width, at least 30 or 40 feet. (Sp. 5294.) Its direction is W. 30° S. The central part is rather coarse textured, firm, and fresh, while along the contact with the gabbroid rock it is rather finely crystalline. Another dike (sp. 5295), exposed in several places near the Pillsbury grain elevator, is of nearly equal extent. An examination of the rocks constituting these dikes shows the feldspars to be somewhat altered. They carry some small grains of hornblende, and are literally colored brown by the numberless granules, which could not be resolved with an immersion lens. Their color and the general aspect of the rock lead to the view that they are the same substance which has been mentioned as occurring in the fresh, ophitic, diabase dikes. The augite has entirely disappeared, and its place is now occupied by hornblende lying in fine and irregularly distributed grains. In places these grains of hornblende include numberless minute black particles. Where biotite is seen, it lies near the corroded particles of iron pyrites.

In the south side of this same section (34) lie other dikes having the same general macroscopic characters as those named. A slide made of the contact material between one of these dikes and the country gabbro-schist shows a very sharp contact (sp. 5294). The gabbro-schist and the dike show an entire alteration of the pyroxenic constituents into finely granular hornblende and into an abundance of fresh-looking plagioclastic feldspars. The dike material is finely crystalline and the plagioclase is in part porphyritic. A very fine texture is noticeable along this contact, which does not appear in the middle of the dike, and a belt of finely granular quartz forms an almost complete zone of separation between the dike and the country rock (see Pl. XXVI, *A*).

Along the river's edge and near the highway which leads out of Granite Falls toward the northwest are several dikes, some of considerable width. They are seen in that portion of sec. 28 lying south of the Minnesota River, and along the northern border of sec. 33. In the last-named section three of four dikes are nearly parallel as they stretch across the brow of a hill. Their general direction seems to be S. 40° W. Several minor dikes show considerable variation from this course. In mineral composition they are all essentially the same.

In Granite Falls a narrow dike 5 inches wide was sampled (sp. 5432), which macroscopically shows a distinct porphyritic structure. A microscopic examination shows that this appearance is due to nests of hornblende granules within a matrix of plagioclase, hornblende, and biotite. In their distribution these granules mark the form of some preexisting crystals which might have been olivine, thus presenting a rock like that at Sauk Rapids, where olivine crystals are still clear and distinct in a porphyritic rock occurring as a narrow dike in the hornblende-biotite-granite of the Sauk Rapids granite quarry.

Between the fresh dikes and the much-altered ones above described

are many intermediate stages, in which the feldspars are tinged with alteration and the augites show hornblende around their borders and along cracks within the grains. The phases of alteration, while varying slightly in some details, have their broader characters in common, and represent every stage from the fresh augite to the clear hornblende.

MONTEVIDEO DISTRICT.

Around Montevideo (see Pl. XI) there are several dikes of some lithologic interest. They lie in the bottoms south of the railroad track, in secs. 20, 21, and 34, T. 117 N., R. 40 W. They are of diverse widths and vary in degree of preservation. With a single exception, so far as observed, they stand in vertical positions in the rocks. This exception is in a railway cut in sec. 20, where a dike a few inches in width follows the bedding of the red acidic gneiss of the district.

Where these dikes are narrow, as in sec. 34 (sp. 5299, 5300), they show the total disappearance of augite and the plentiful occurrence of needles of apatite in every part of the section. The alteration products of the augite are hornblende and biotite, nearly in the proportion of 2 to 1 in the slides examined. While many localities show the direct formation of hornblende alone from the augite, these rocks exhibit a remarkably even distribution of the biotite, not only around the hornblende areas but within them as well.

In the broader dikes (sp. 5303) the individuals of all the mineral constituents are much larger. The feldspars, which frequently lie in nests of twinned forms, are loaded with minute granules of hornblende scattered as an impurity through their central portions. These hornblende granules all seem to lie in the same crystallographic direction in any given feldspar. A characteristic feature of these feldspars is the brown color which appears in almost every section. In places—for instance, where the hornblende granules appear in their cores—the brown color is exceedingly slight, and as a rule the feldspars are more mashed around the borders of the areas, although this condition can not be clearly defined. Twinning in very striking forms is shown in the larger feldspars, combinations after the pericline and albite law being frequent. A zonal structure is conspicuous in many of them. It appears to be of two kinds: first, a structure due to interruptions in the growth of the crystal grains; and, second, where additions of a secondary nature were made to the original feldspar individuals after the consolidation of the rock and during its alteration. Occasionally the feldspar areas show the presence of kaolinic material. The augites have begun to change to hornblende, as their rims of finely crystalline, green material clearly show. In places the alteration is complete. (See Pl. XXV, *A*.) Olivine is not present, and no cores of that mineral were noticed, although many areas of secondary material occur, particularly in that part of the dike near the contact. These areas are

small, and in all cases are composed of a radiating viriditic mineral having the general characters of hornblende and in every respect identical with the rims around the olivine cores of the two ophitic dikes of Granite Falls. Little biotite is seen. Pyrite is present, but not in abundance.

EXCEPTIONAL DIKES.

Besides the diabases described in the foregoing paragraphs, there were noted two or three areas of somewhat different rocks. Although these exposures are of the diabasic type, they are so different from the normal dikes of the valley that they will be considered separately.

On the south side of the river, in secs. 14 and 15, T. 112 N., R. 34 W., there are large masses of this rather coarse-grained rock. A gneissic structure is pronounced. This structure is developed, not through any noticeable parallelism in the position of the constituent minerals, but by a distinct segregation of these minerals into bands or laminæ extending considerable distances through the rock.

The field relations of this belt of rocks are very obscure. No contact with other rocks on either side could be seen. At the surface the rock is considerably decomposed, and the reddish hue of much of the feldspars is imparted to it. The weathering produces a rough, uneven surface. While some contortion is noticeable, the general strike of these masses is NE.-SW., with a dip frequently as high as 80° S. Scattered through this rock are inclusions of material more or less feldspathic than the average. To the naked eye the rocks seem to be unusually free from accessory minerals. Here and there small nests of pyrite can be seen, and occasionally a porous condition near the surface points to the dissolving and carrying away of some mineral more readily acted upon than most of the constituents.

While the texture of this rock is medium, there is a peculiar and apparently secondary structure running through it, seen in every expoure. This consists chiefly in the presence of broad, thin leaves of the hornblende. This mineral in its formation seems to have been arranged with many of its individuals having their axes, *c*, in a common direction within considerable areas, 1 and 2 inches across, thus giving the impression of large individuals. This impression is intensified by the reflection of the light at the same angle from a large number of small grains breaking and cleaving in the same plane. Their composite character can be best seen where the feldspars predominate, since color contrasts serve to bring out more sharply the outlines of the areas. The fresh fracture, when studied with low power, has a decidedly granular appearance, with the grains all presenting their cleavage planes at precisely the same angle. Between these grains can be detected the feldspars, the epidote grains, and, in the more weathered portions, biotite folia. While the length and breadth of these segregations are considerable, they are very thin. Looked at on edge,

they are mere dark lines through the field of light-colored constituents. This condition of itself would give a lamination to the rock, did all these tabular segregations lie in one general direction, which is not the case.

While these are not porphyritic individuals of hornblende, they seem to have a relation to the arrangement of the augite peculiar to certain eruptive rocks. This arrangement suggested to Pumpelly,[1] as he studied the melaphyre of Lake Superior, the significant term "luster-mottling." This structure has since been observed in contemporary diabases and gabbros, and in gneissic rocks of still greater age.[2]

A slide made from the lighter-colored bands would show probably 75 per cent of feldspar and epidote, the chief alteration product of the feldspar, and one from the darker band an equal proportion of hornblende. A greenish color pervades many of the feldspar individuals, especially those of the laminæ poor in hornblende. This is due, doubtless, to the epidote present. In places, too, the hornblende itself has this pale-green tone. Where there are variations toward a veinlike character, the feldspars are red in color and the hornblende exhibits well-formed crystals.

The only exposure of these exceptional dikes noted on the north side of the river is in the bottoms in sec. 34, T. 112 N., R. 33 W. The area is small, lying beside a small circular lake and not more than 15 feet above the surface of the water. While the rock is generally massive, it shows in places a distinct lamination, due to the segregation of the darker-colored constituents into bands of varying thickness and varying distances apart. In other places segregations of spherical shape occur; these are of a lighter color and somewhat harder than the body of the rock, so that they resist weathering better and thus stand out in knobs. While the mass is somewhat shattered, it is much less so than are the normal dikes of the valley.

The microscopic characters of the exposures are those of very much altered rocks. The feldspars are so far altered to kaolin and epidote that near the edges of three or four individuals only could the extinction angle of the labradorite group be made out. The diabasic structure is seen, although in some sections a greater breadth is noticed than in the feldspar individuals of the ordinary dikes of the valley. In many cases crystal outlines occur, or even perfect porphyritic crystals showing the prismatic, pyramidal, and pinacoidal faces. In the gneisses, as has been stated, there are frequently secondary feldspars, doubtless resulting from the degradation of the primary ones. Here, however, the secondary minerals are in no observed instances feldspars. As a rule the borders of the feldspar crystals are in a much better state of

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[1] Metasomatic development of the copper-bearing rocks of Lake Superior, by R. Pumpelly: Proc. Am. Acad. Arts Sci., Vol. XIII, 1878, p. 260. Lithology of the Keweenawan system, by R. Pumpelly: Geol. Wisconsin, Vol. III, 1880, p. 33. Preliminary description of the peridotytes, gabbros, diabases, and andesytes of Minnesota, by M. E. Wadsworth: Bull. Geol. Nat. Hist. Survey Minnesota, No. 2, 1887, p. 107.

[2] The copper-bearing rocks of Lake Superior, by R. D. Irving: Mon. U. S. Geol. Survey, Vol. V, 1883, p. 73. Ibid., p. 42. Notes of a geologic excursion into central Wisconsin, by C. W. Hall: Bull. Minn. Acad. Nat. Sci. Vol. III, No. 2, p. 25.

preservation than are their centers, a fact of very wide application among the crystalline rocks of the Northwest.

Quartz is reasonably abundant. Everywhere it is a secondary mineral, free from inclusions and very limpid. It is in pegmatitic forms, occupying interstices between the feldspars, or in granular condition it forms the lenticular fillings seen between the biotite folia. In the first-named position it exhibits sharply marked boundaries, and all the different areas over a considerable surface lie in the same crystallographic position and extinguish together. This is illustrated in Pl. XXVI, *B*, from a thin section cut from specimen 5400. The lenticular fillings are almost as frequent as the areas of biotite. They are wedged in between the folia and oftentimes stretch them to a considerable extent. In places other minerals serve as such filling, particularly epidote and calcite, but these minerals in this situation are rare as compared with quartz. While these fillings are granular, the grains very generally extinguish parallel with the biotite.

Of the basic constituents in the slides examined, augite remains in one or two small cores only, surrounded by secondary hornblende. Many areas of this last-named mineral containing no augite show by the granular and impure condition of their central portions that they are of secondary origin, and the evidence of scores of specimens taken throughout the valley points to preexisting augite or diallage individuals from which the hornblende was derived. In addition to the larger areas mentioned, many small individuals of hornblende lie scattered about. These may arise from the transfer of material during the alteration of the rock.

Besides the hornblende mentioned as an alteration product, chlorite is rather abundant. It occurs in clustered areas of radial, fibrous spherules, which lie in proximity to the hornblende areas and the epidote masses alike. Other areas are found in the midst of the decomposed feldspar individuals. Both in its occurrence here and in its arrangement in the rock, the chlorite seems to unite this rock closely to the gneissic rocks figured from Tracy's place, only 3 or 4 miles away on an air line. (Pl. XVII, *A*.)

Epidote is an alteration product of considerable importance in these rocks. It is probably derived in large part from the decomposition of the feldspars. These, as has just been stated, belong chiefly to the labradorite type, thus containing sufficient lime for the formation of the epidote and the small quantity of calcite present. While much of the epidote lies within and around the changed feldspar areas in a way to suggest its origin from that mineral, as maintained by Chester in his description of the Delaware gabbros,[1] and by Williams in his work on the gabbros in the neighborhood of Baltimore,[2] that portion

[1] The gabbros and associated rocks in Delaware, by F. D. Chester: Bull. U. S. Geol. Survey No. 59, 1890, p. 35.

[2] The gabbros and associated hornblende rocks occurring in the neighborhood of Baltimore, Md., by G. H. Williams: Bull. U. S. Geol. Survey No. 28, 1886, pp. 31-32.

of the epidote which occurs in largest individuals and in strongest color is more intimately associated with the hornblende in situation and possibly in derivation.

No analysis of this rock as a whole, or of any of its constituent minerals, was made, so that no considerations based on its composition can be stated. However, taking the analyses of many samples from the tables in Dana's System of Mineralogy,[1] we glean the following facts: The average per cent of calcium oxide, CaO, in the augite of metamorphic and eruptive rocks, computed from the twenty-three analyses given, is nearly 22 per cent. The average of seven analyses of hornblende gave slightly over 13 per cent of calcium oxide, which leaves an excess to supply the epidote, after furnishing all necessary for the hornblende in the change of augite into hornblende, which is assumed. Nowhere are the individuals of epidote of large size, but everywhere they are granular. Twinning striæ were not seen. In no other rock of the valley was so large a proportion of the mineral epidote observed, and in no other examined was the feldspathic constituent so completely obliterated as in this, save, perhaps, in those gneisses of Redwood Falls and Birch Cooley where entire rock masses have been converted into an impure kaolin.

Calcite also occurs in this rock. Its characters are those usually seen in this mineral in the altered crystalline rocks. While sometimes it may be a filling for primary or secondary cavities[2] in normal eruptive rocks of even very ancient age, as in the Keweenawan and associated rocks of the Lake Superior region, in this case it plainly fills interstices between the existing minerals which have been formed by the alteration of the original plagioclases and pyroxenes. It most frequently occurs around the segregated hornblende, chlorite, and epidote areas, a circumstance which strongly suggests that the larger part of it was formed by the alteration of the augite. Such a change Pumpelly noted among the melaphyres of Lake Superior as long ago as 1878.[3] Occasionally twinning striæ appear, but they are comparatively rare. The mineral, as a rule, is very finely granular.

Calcite, as a decomposition product in these rocks, occurs also in the midst of the feldspar areas. Its characters there are precisely those named in interstitial situations. As a result of alteration this mineral has been seen almost nowhere else in the valley except in rocks of the same general character south of the river. Its rarity confirms the assertion of Rosenbusch, who regards it as an alteration product from lime silicates.[4] A few small crystals of apatite are present.

The light-colored spherical nodules mentioned as included in places in this rock appear to carry a much smaller proportion of hornblende

[1] A System of Mineralogy, by J. D. Dana, 5th ed., 1868, pp. 218, 238.

[2] Preliminary description of the peridotytes, gabbros, etc., of Minnesota, by M. E. Wadsworth: Bull. Geol. Nat. Hist. Survey Minnesota, No. 2, 1887, p. 82.

[3] Metasomatic development of the copper-bearing rocks of Lake Superior, by R. Pumpelly: Proc. Am. Acad. Arts Sci., Vol. XIII, p. 268.

[4] Mikroskopische Physiographie der Mineralien und Gesteine, by H. Rosenbusch, 3d ed., 1892, Vol. I, p. 404.

and biotite than the main mass of the rock. The feldspar in these nodules is considerably fresher than elsewhere, frequently showing the twin striation with sufficient clearness for measurement, and the epidote is much more thickly scattered throughout the mass. Calcite is very infrequent in these nodules. Magnetite and pyrite are scarcely seen.

In the village of Cottonwood, T. 113 N., R. 40 W., the boring of an artesian well was attempted in 1895. At a depth of 280 feet granite rocks were reached. These were penetrated 190 feet. At some point within this distance a band of dark-green, finely textured rock was bored through. One piece, 3½ inches long, was brought up by the slush bucket (sp. 5768). Its surface has a decidedly greasy feel,but a rough fracture is disclosed by breaking. Its specific gravity is 2.85.

Microscopically the rock is an altered diabase. The two principal constituents, labradorite and augite, still remain in fragments sufficiently large and fresh for identification. The augite has a light-brown color, extinguishes at an unusually low angle, and is largely altered into chlorite, hornblende, and associated products. The feldspars are labradorites, with a prevailing low extinction, indicating the presence of soda, an indication borne out by the presence of a suassuritic mineral among the products of alteration. Magnetite is plentiful, with its clearly defined crystal contours.

PLATE XVI.

PLATE XVI.

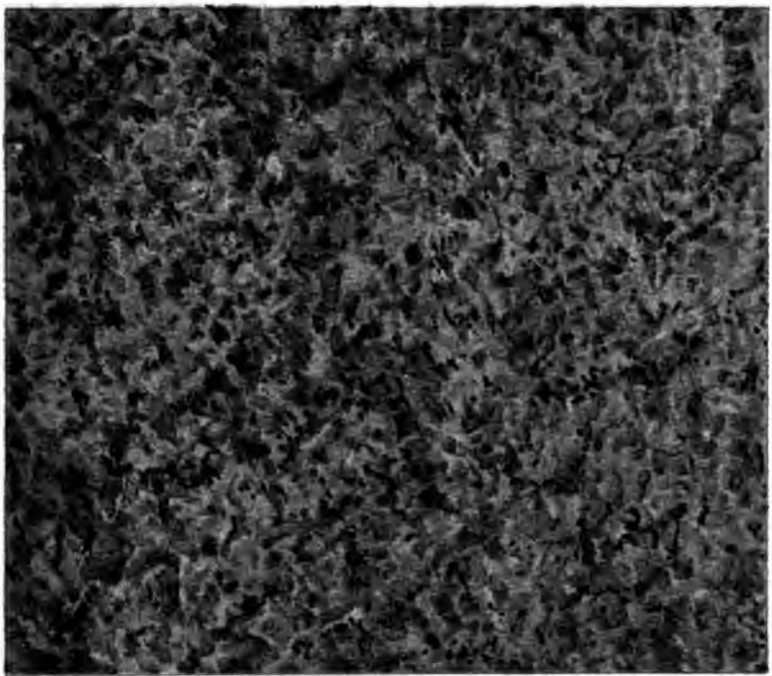
Fig. *A*. Granite-gneiss, a block 3½ by 4 inches, from the Ortonville quarries.

The light pink represents quartz with the color of underlying feldspar seen through the transparent grains; the dark pink the second feldspars; the black the few scattering folia of biotite with, rarely, grains of secondary hornblende.

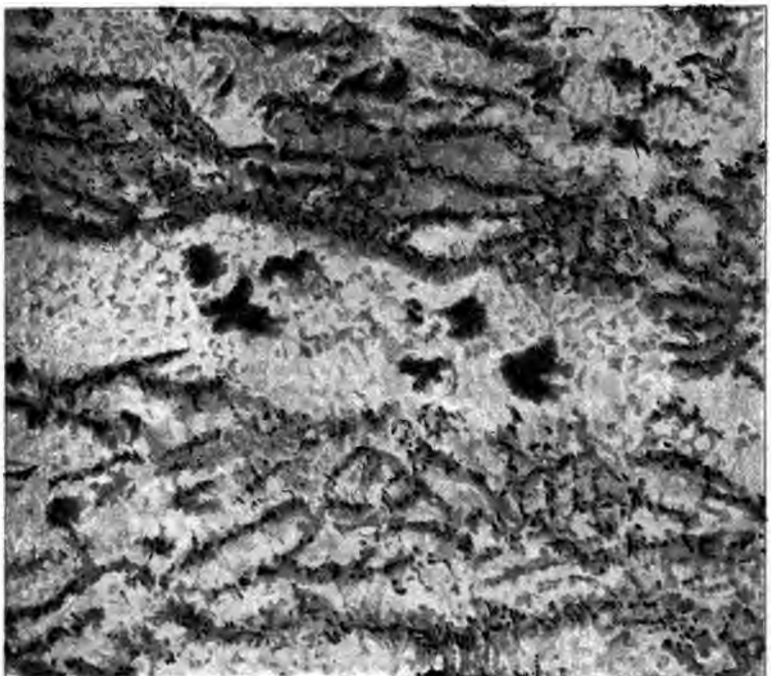
Fig. *B*. Contorted hornblende-biotite-gneiss, a block 3½ by 4 inches, from the quarries at Morton.

The white represents the quartz and a portion of the feldspars; the pink that portion of the feldspars slightly stained, and the black biotite and hornblende in segregations and bands, with smaller grains in places more evenly distributed among the quartz and feldspars.

See p. 73.



(A)



(B)

JULIUS BIEN & CO. N.Y.

(A) GRANITE - GNEISS

(B) CONTORTED HORNBLENDE - BIOTITE - GNEISS

PLATE XVII.

PLATE XVII.

Fig. *A*. Chloritic gneiss. In the upper part of the figure the radial arrangement of the chlorite is seen.

Specimen 5206, slide 1780, × 55, in ordinary light.

The lower part exhibits slender vermiform crystallizations in a field of quartz. (1) Chlorite, (2) quartz, (3) sphene.

Specimen 5729, slide 9478, × 250.

See p. 59.

Fig. *B*. A fresh unaltered hypersthene-gabbro.

(1) Anorthite-labradorite feldspar, very fresh; (2) hypersthene, scarcely altered; (3) small, scattering folia of biotite.

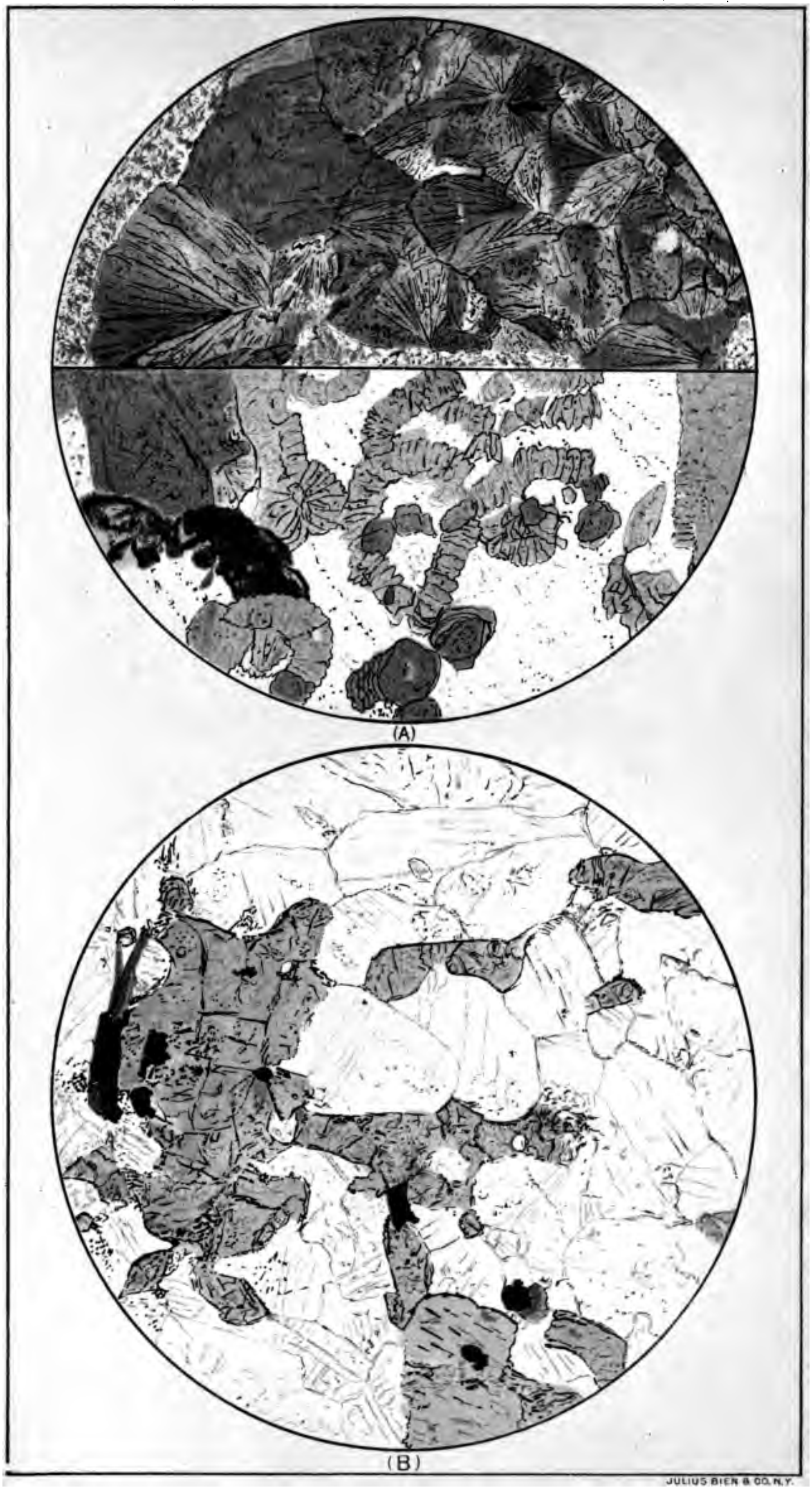
Specimen 5335, slide 2263, × 100.

See pp. 91, 95.

(A)

(B)


(B)



(A)

(B)

JULIUS BIEN & CO. N.Y.

(A) CHLORITIC GNEISS (B) HYPERSTHENE-GABBRO

PLATE XVIII.

PLATE XVIII.

Fig. *A*. Hornblende-biotite-granite-gneiss. Muscovite, apparently formed by the alteration of an albite inclusion in microcline.

(1) A microcline individual much larger than the entire field; (2) an albite inclusion entirely surrounded by the microcline individual; (3) muscovite within the albite and apparently derived from its decomposition; all portions extinguish together; (4) other areas of muscovite; (5) biotite.

Specimen 5338, slide 2265, × 53, in polarized light.

See p. 54.

Fig. *B*. Hornblende-biotite-gneiss. Vermicular quartz, within an area of albitic feldspar.

(1) Plagioclastic feldspar of low extinction; (2) canals filled with quartz in vermicular arrangement within the feldspar.

Specimen 5396, slide 2288, × 250, in polarized light.

See pp. 51, 67.

(A)

(B)

JULIUS BIEN & CO. N.Y.

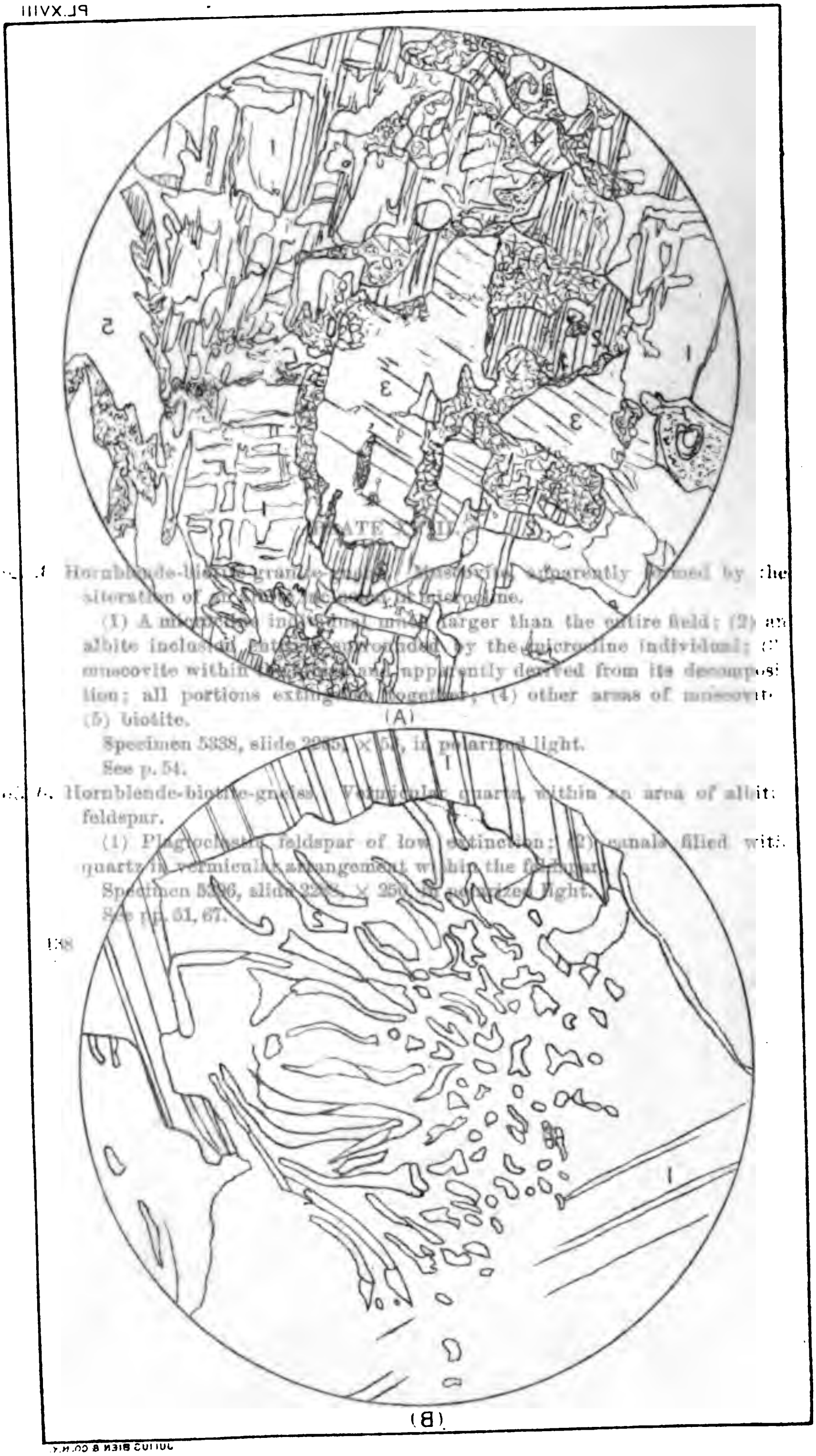


PLATE XVIII.

FIG. A. Hornblende-biotite-granite-gneiss. Muscovite apparently formed by the alteration of an albite inclusion in microcline.

(1) A microcline individual much larger than the entire field; (2) an albite inclusion entirely surrounded by the microcline individual; (3) muscovite within the albite and apparently derived from its decomposition; all portions extinguish together; (4) other areas of muscovite; (5) biotite.

Specimen 5338, slide 2285, × 55, in polarized light.

See p. 54.

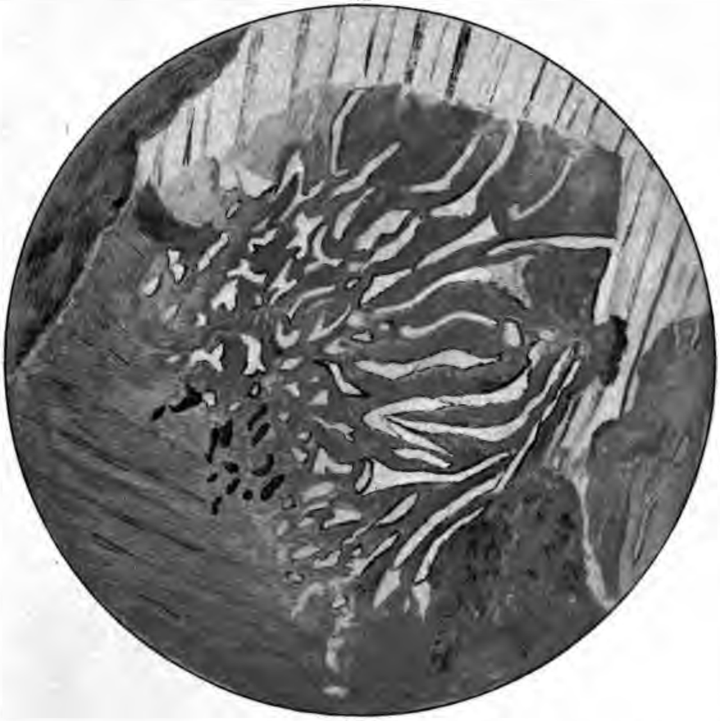
FIG. B. Hornblende-biotite-gneiss. Vermicular quartz within an area of albite feldspar.

(1) Plagioclastic feldspar of low extinction; (2) canals filled with quartz in vermicular arrangement within the feldspar.

Specimen 5396, slide 2283, × 250, in polarized light.

See pp. 51, 67.

(A)

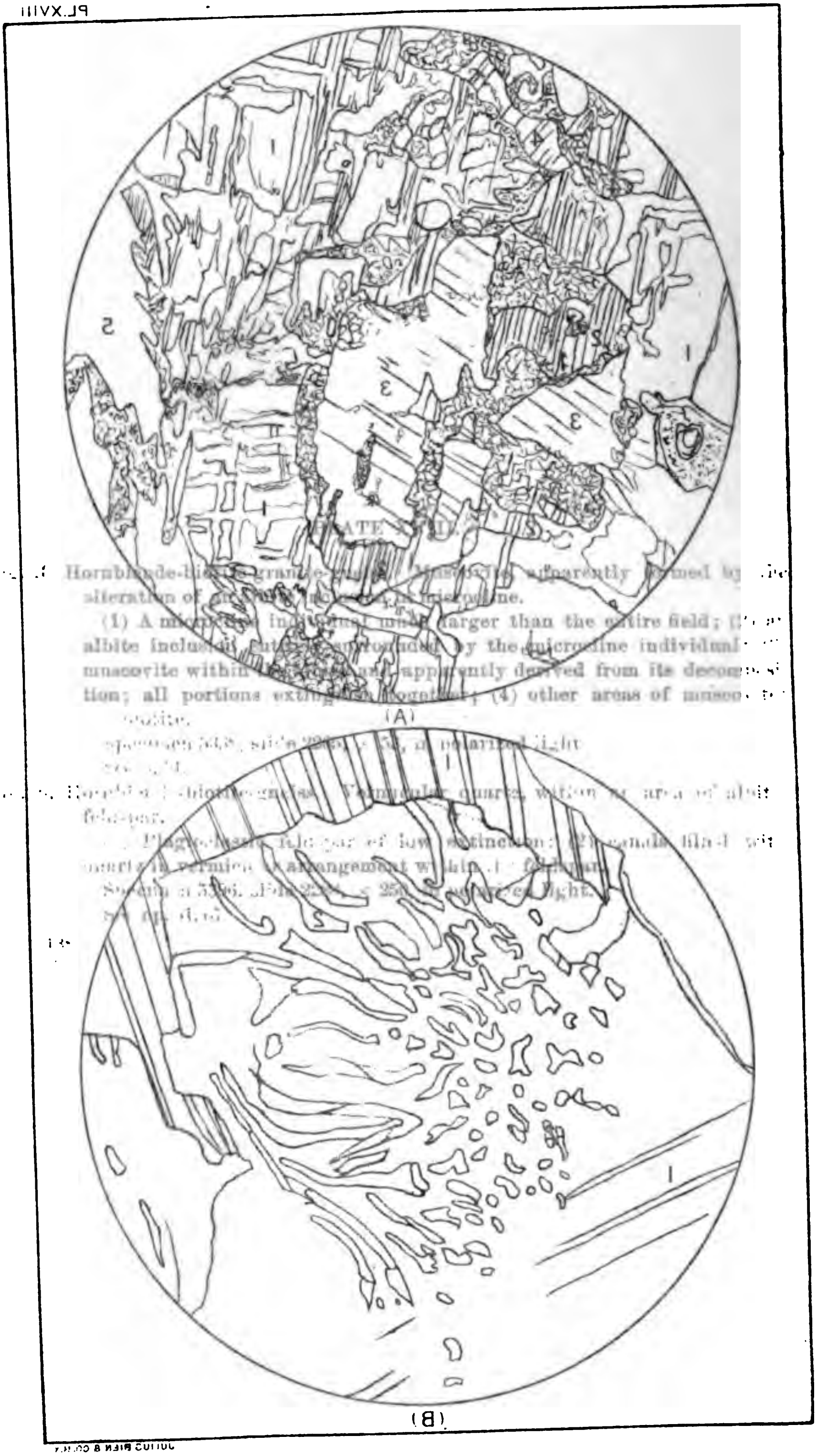


(B)

JULIUS BIEN & CO. N.Y.

(A) HORNBLENDE-BIOTITE GNEISS (B) VERMICULAR QUARTZ

PL. XVIII



JULIUS BIEN & CO.

(A)

(B)

JULIUS BIEN & CO. N.Y.

(A) HORNBLENDE-BIOTITE GNEISS (B) VERMICULAR QUARTZ

PLATE XIX.

PLATE XIX.

Fig. *A*. Hypersthene-free gabbro-schist. Area of diallage in which alteration to hornblende is begun. Some areas of hornblende can be seen with a low power, but many more can be recognized under higher magnification, while a green color shows that incipient alteration pervades the entire field of diallage.

Specimen 5185, slide 1765, × 100.

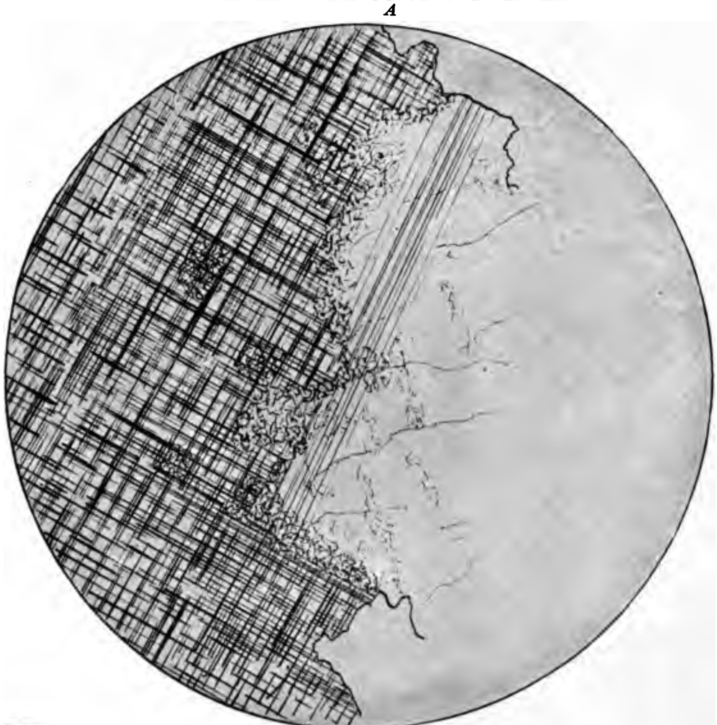
See pp. 80, 99.

Fig. *B*. Hornblende-biotite granite-gneiss. Contact zone between microcline and oligoclase where the boundary is not distinct. A finely granular mineral not easily identified lies between the two recognizable feldspars. That either is secondary to the other does not appear.

Specimen 5320, slide 2457, × 75.

See p. 52.

A



B

A, HORNBLENDE IN FINE GRANULES WITHIN A LARGE PLATE OF DIALLAGE.
B, CONTACT ZONE BETWEEN MICROCLINE AND OLIGOCLASE.

PLATE XX.

PLATE XX.

Fig. *A*. Porphyritic hornblende-biotite-gneiss. Radially arranged individuals of biotite within a quartz individual partially filling a minute fissure.

Specimen 5262, slide 2442, × 350.

See p. 53.

Fig. *B*. Hornblende-biotite-gneiss. Microcline occurring in small anhedral individuals within a field of orthoclase. All the microcline areas extinguish together, but in this case not in the same direction as the orthoclase.

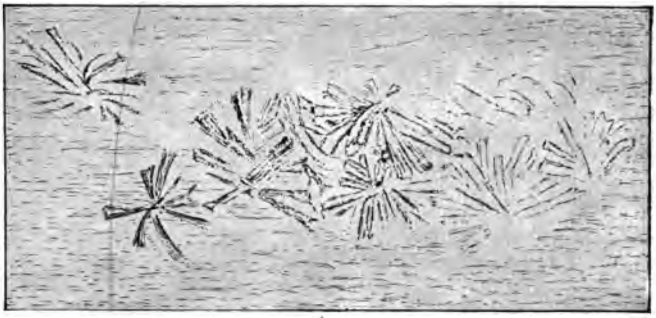
Specimen 5315, slide 2254, × 150.

See pp. 52, 53.

Fig. *C*. Hypersthene-free gabbro-schist. Individual of biotite carrying lenses of quartz wedged in between the biotite folia. The quartz is secondary and undoubtedly the biotite is also.

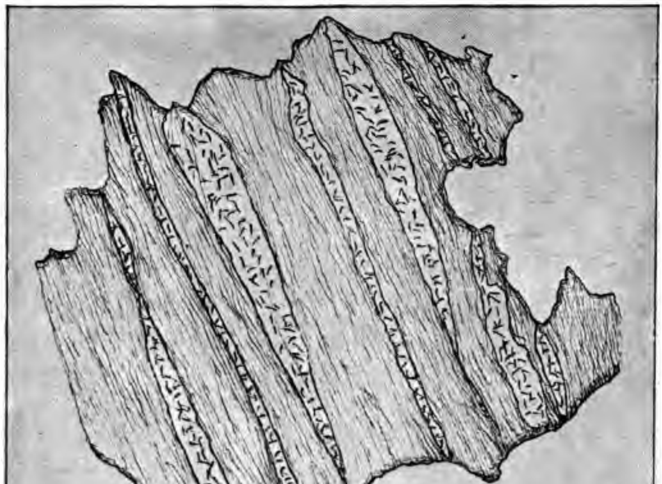
Specimen 5186, slide 4432, × 120.

See pp. 54, 99.



A

B



C

A, BIOTITE IN RADIAL CLUSTERS WITHIN QUARTZ.
B, MICROCLINE WITHIN OLIGOCLASE.
C, LENSES OF QUARTZ IN BIOTITE.

PLATE XXI.

PLATE XXI.

Fig. *A*. Hypersthene-gabbro. There has resulted a partial alteration of the pyroxenic constituents into brown hornblende.

(1) Hypersthene, tolerably fresh in the centers of the fragments into which it has been fractured; (2) hornblende, apparently resulting from the decomposition of the hypersthene: it appears also as a filling in all the fractures within the hypersthene individuals; (3) labradorite; (4) augite.

Specimen 5278, slide 2257, × 48.

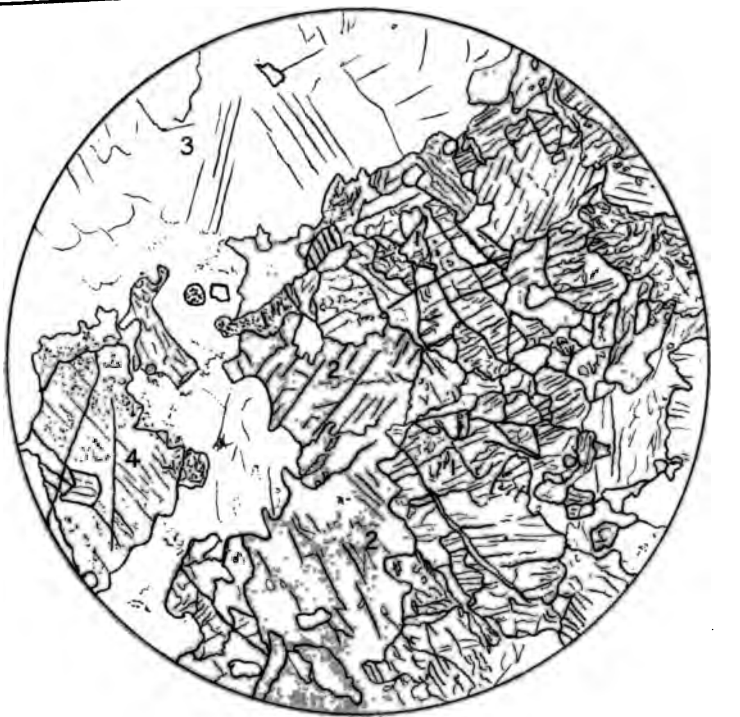
See pp. 86, 91.

Fig. *B*. Gabbro-diorite. The pyroxenic constituents are completely altered to green hornblende.

(1) Hornblende, derived undoubtedly from the decomposition of pyroxenic constituents; (2) feldspar of the anorthite-labradorite type; (3) small grains of magnetite.

Specimen 5418, slide 4442, slightly magnified.

See pp. 91, 107.



(A)

(B)

JULIUS BIEN & CO. N.Y.

PL. XXI.

PLATE XXI.

Hypersthene-gabbro. There has resulted a partial alteration of the pyroxenic constituents to hornblende.

(1) Hypersthene, remaining fresh in the centers of the fragments into which it has been divided; (2) hornblende, apparently resulting from the decomposition of the hypersthene; it appears also as a filling in all the fractures within the hypersthene individuals; (3) labradorite; (4) augite.

Specimen 5278, slide 2257, × [illegible].

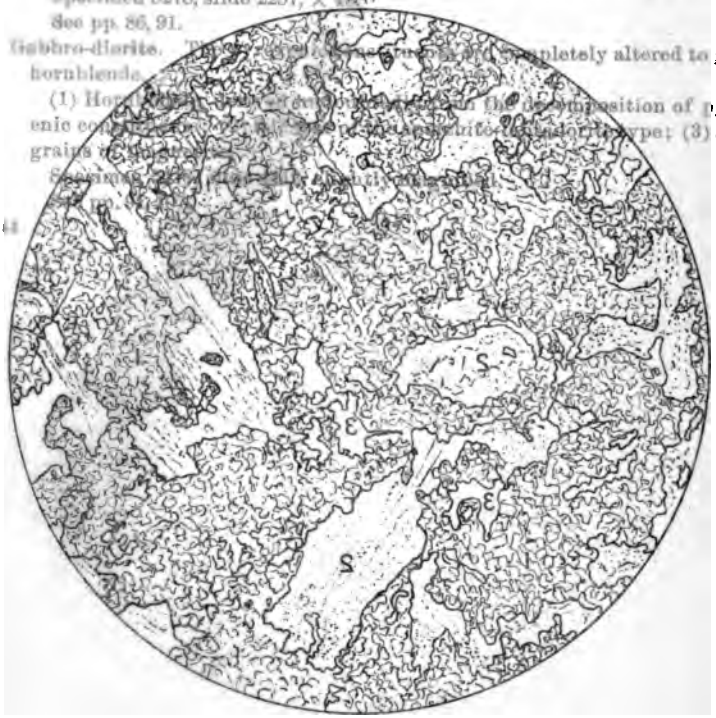
See pp. 86, 91.

(A)

Gabbro-diorite. The [illegible] completely altered to green hornblende.

(1) Hornblende [illegible] the decomposition of pyroxenic constituents; (2) [illegible] type; (3) small grains [illegible]

Specimen [illegible]



(B)

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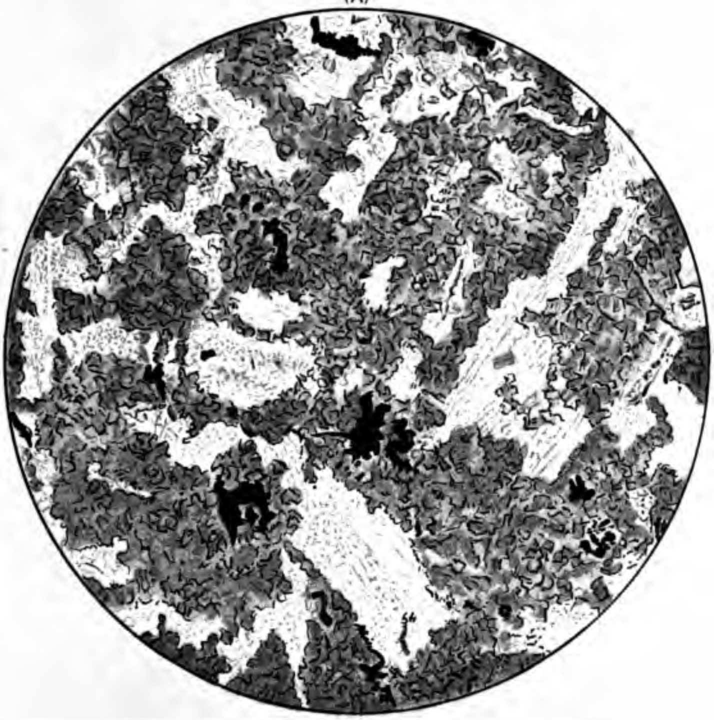
(A)



(B)

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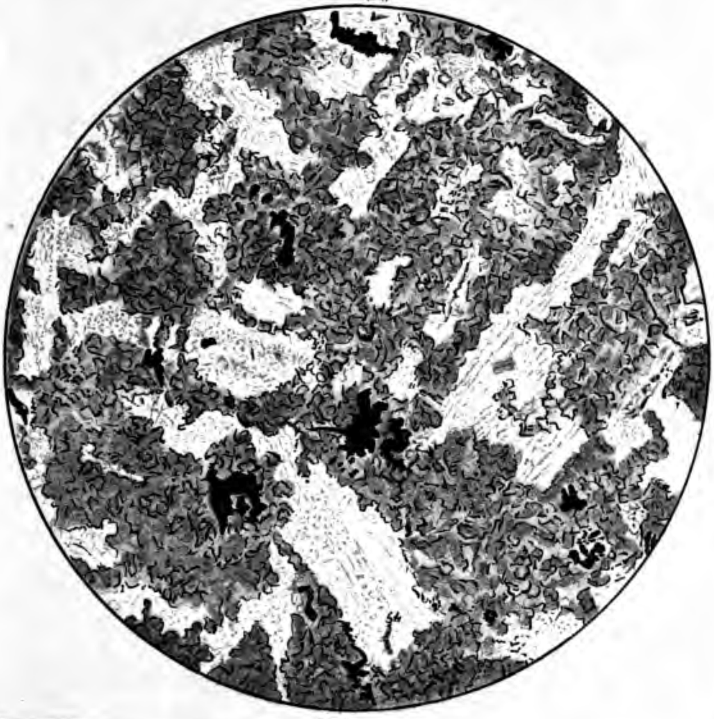
(A) HYPERSTHENE GABBRO (B) GABBRO DIORITE

(A)

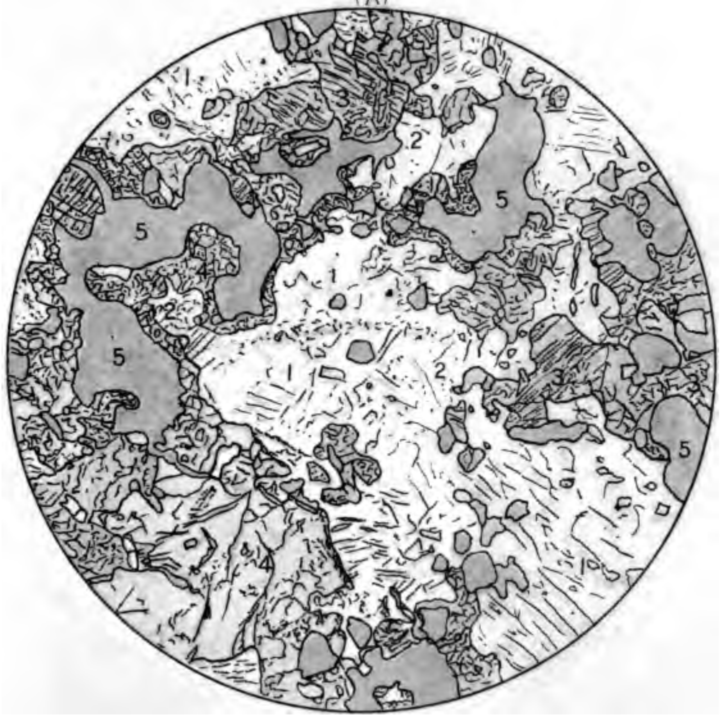


(B)

JULIUS BIEN & CO. N.Y.

(A) HYPERSTHENE GABBRO (B) GABBRO DIORITE.

(A)



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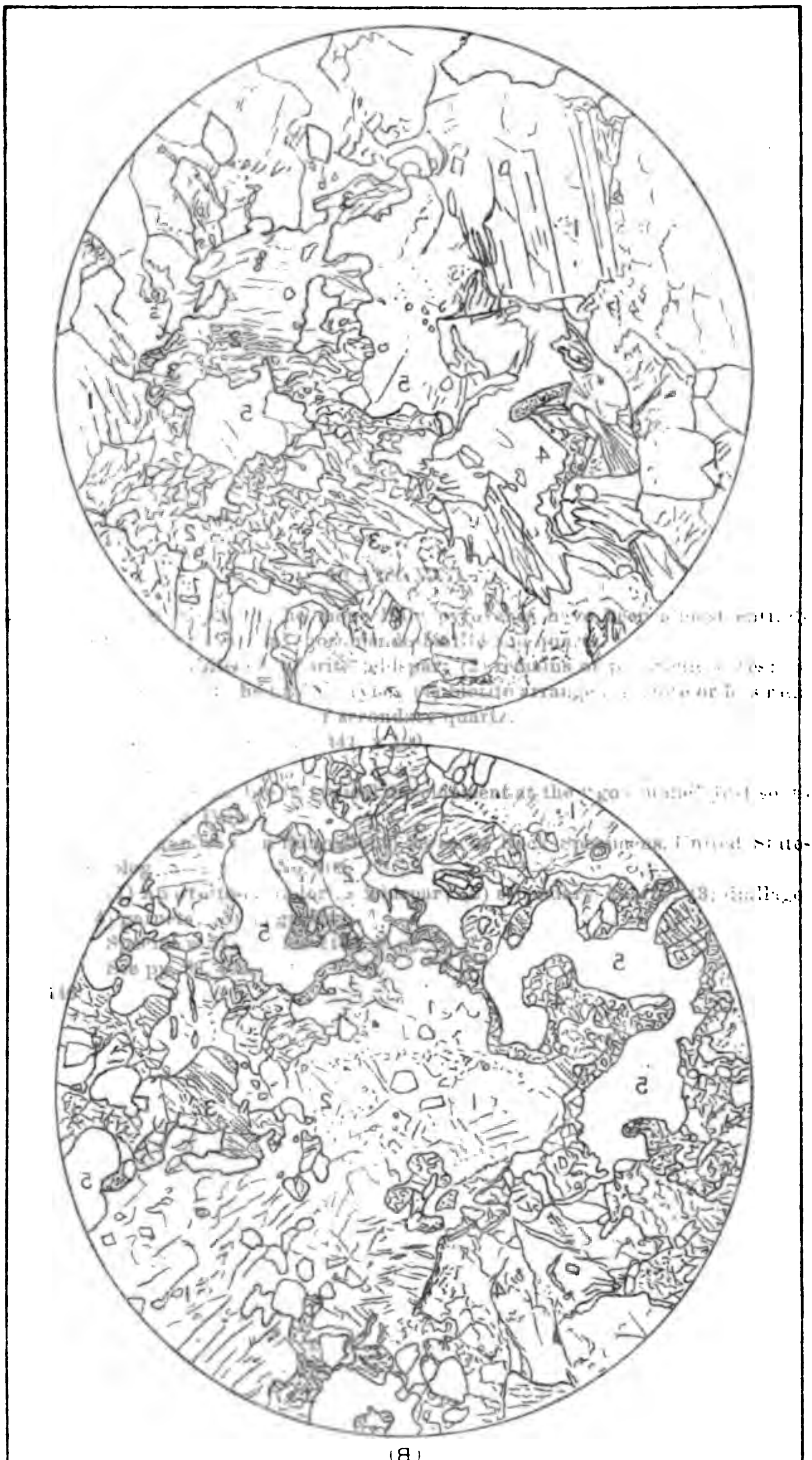
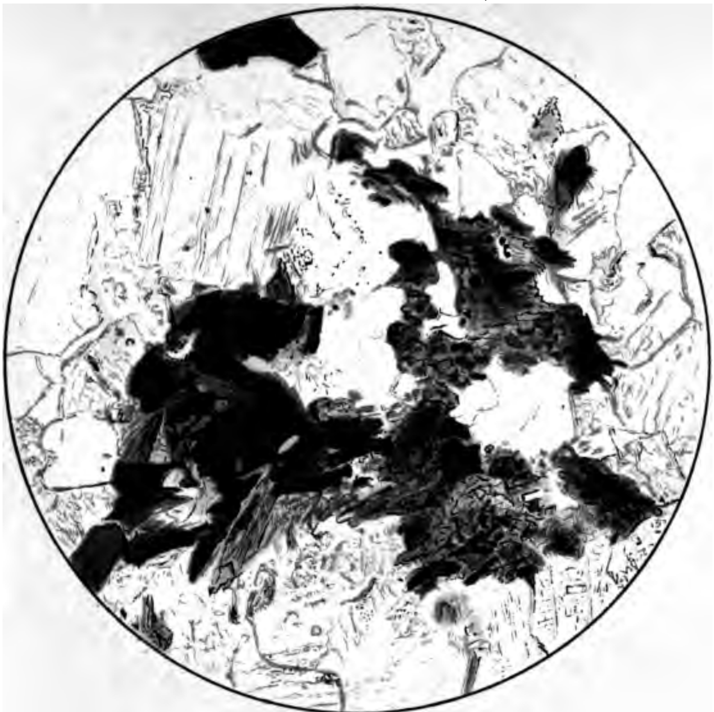
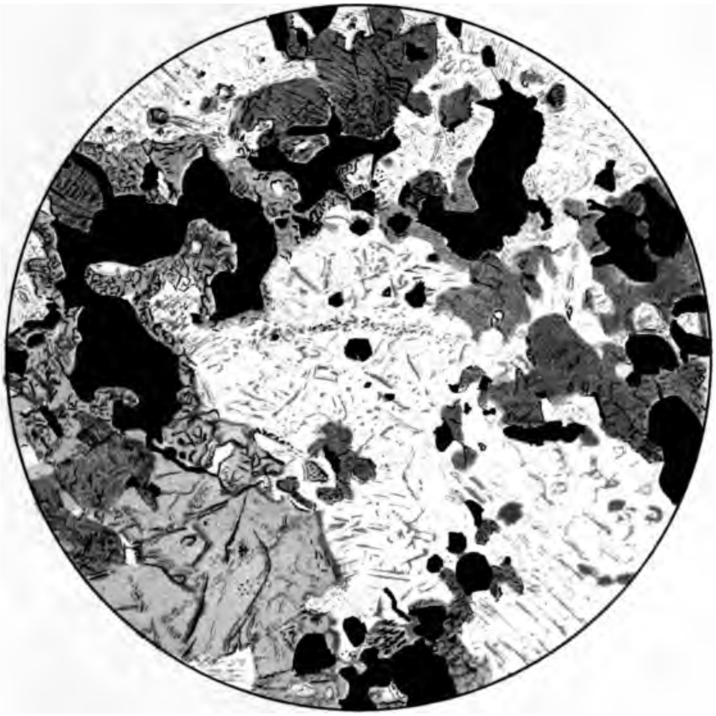

(A)
(B)



(A)



(B)

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(A) ALTERED GABBRO (B) GARNETIFEROUS GABBRO

PLATE XXIII.

PLATE XXIII.

Fig *A*. Altered hypersthene-bearing gabbro-schist. A cluster of minute veins, chiefly of hornblende, occupying intergranular spaces between the individuals of plagioclastic feldspar, and even filling the spaces of fractures pushed open. Vein contents very finely granular.

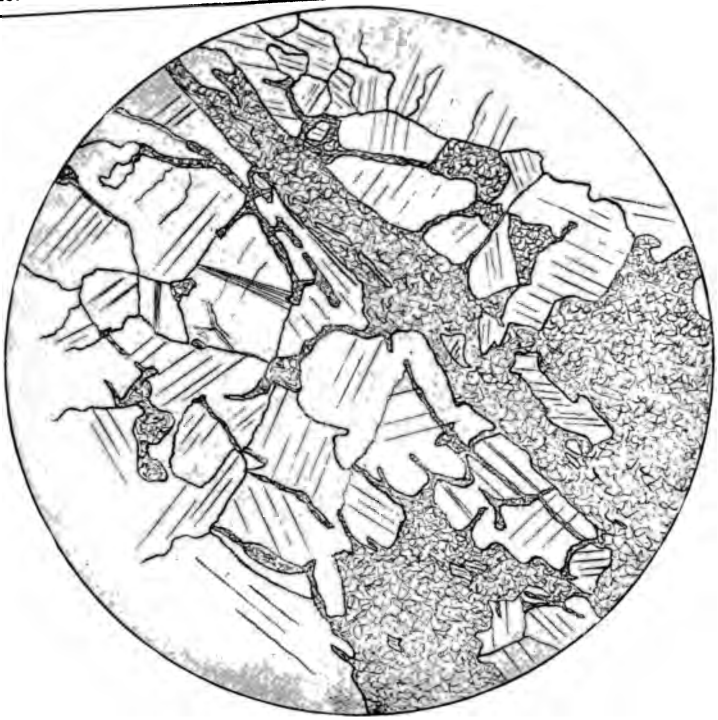
Specimen 5399, slide 2289, × 150.

See p. 85.

Fig. *B*. Hypersthene-free gabbro-schist. Diallage developed locally in large individuals containing within them the other mineral constituents of the rock. An example of poikilitic texture.

Specimen 5199, slide 1775, × 75.

See p. 98.



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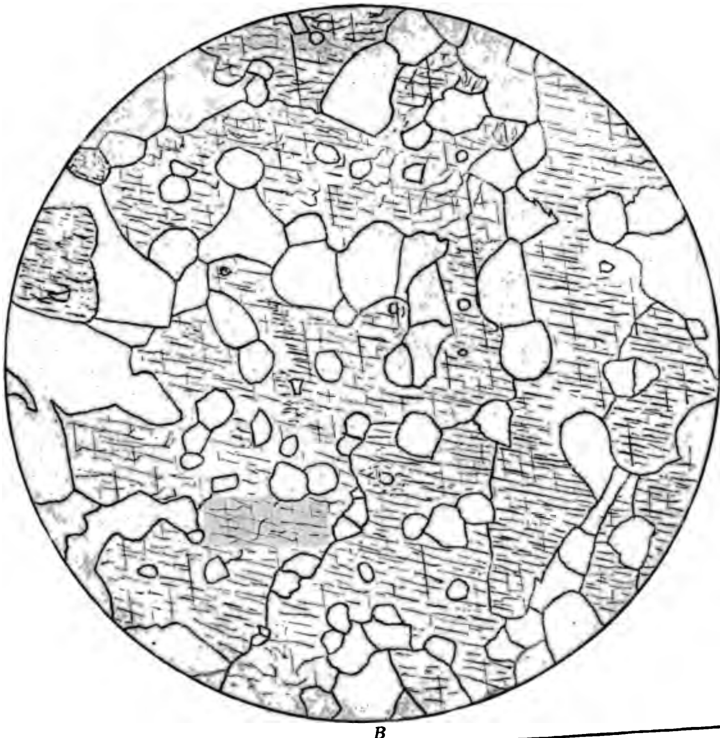


B

A, ANASTOMOSING OF VEINS OF HORNBLENDIC MATERIAL BETWEEN FELDSPARS.
B, DIALLAGE AS A MATRIX CONTAINING THE OTHER MINERAL CONSTITUENTS AS INCLUSIONS.

PLATE XXIV.

PLATE XXIV.

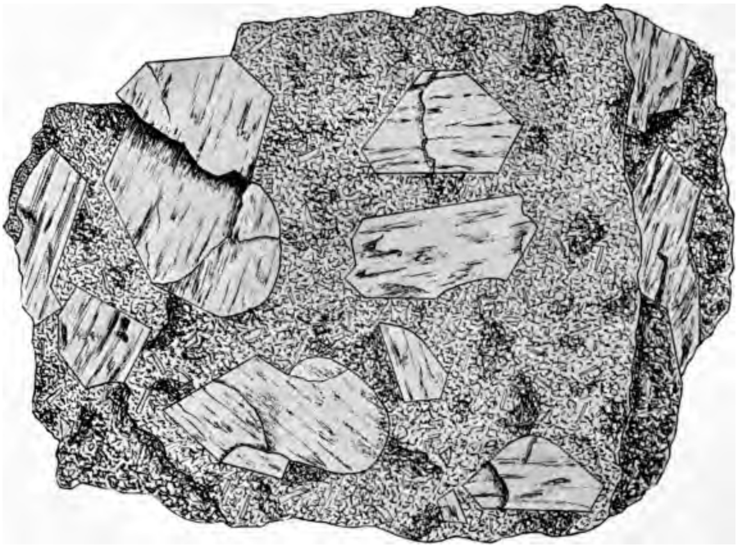
Fig. *A*. Porphyritic gabbro-schist. Hand specimen. The usual constituents, labradorite-anorthite, hornblende, augite, diallage, hypersthene, with accessories, lie in the groundmass, within which are developed the large and well-defined anorthite crystals.

Specimen 5438, natural size.

See pp. 87–89.

Fig. *B*. Porphyritic diorite. Fresh transparent labradorite grains, in which are seen broken apatite crystals so displaced that the fragments are shoved until they overlap one another.

Specimen 5441, slide 9470, × 250.



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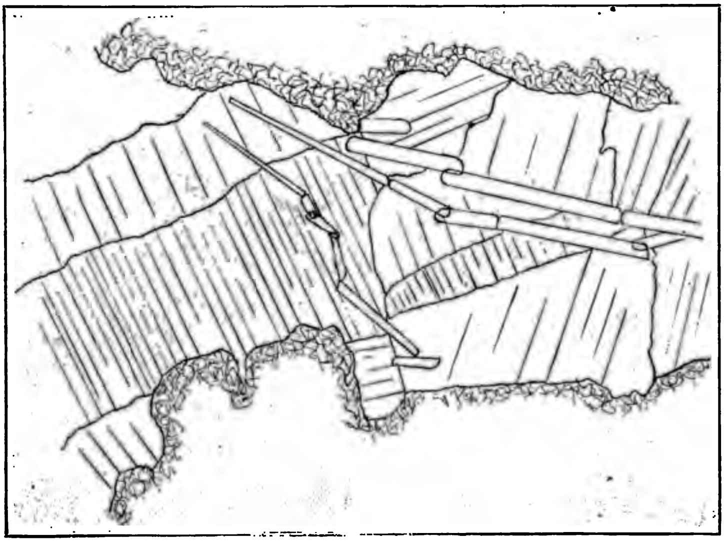
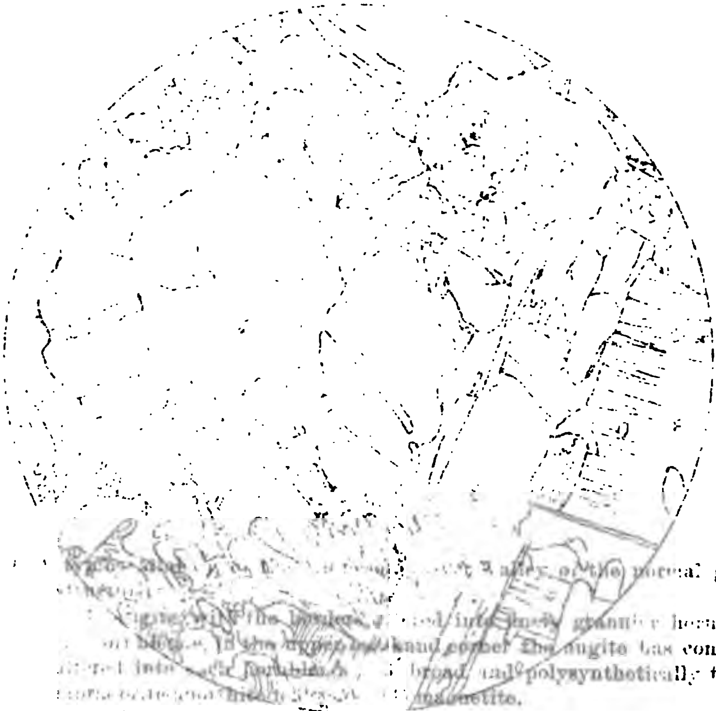
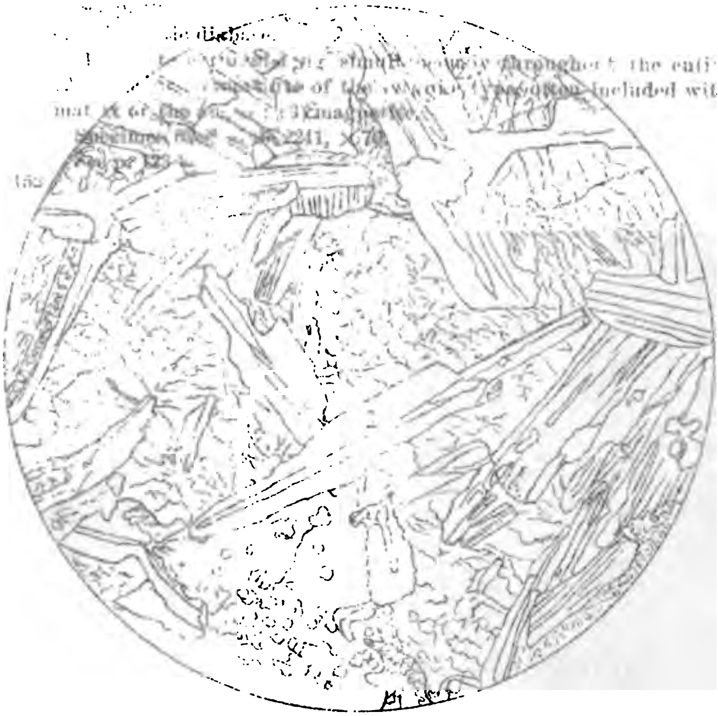


B

A. HAND SPECIMEN OF PORPHYRITIC GABBRO, WEST PART OF GRANITE FALLS.
B. BROKEN APATITE NEEDLES IN LABRADORITE FELDSPARS.

PLATE XXV.





(A)

(B)

JULIUS BIEN'S CO. N.Y.

(A) NON-OPHITIC DIABASE

(B) OPHITIC DIABASE.

PLATE XXVI.

PLATE XXVI.

Fig. *A*. Contact of finely granular diabase dike and hypersthene-free gabbro. The dike is of considerable width and of medium texture away from its contact zones, while near the contact it is porphyritic with labradorite-feldspar individuals. Among the contact minerals occur many clear minute grains of quartz.

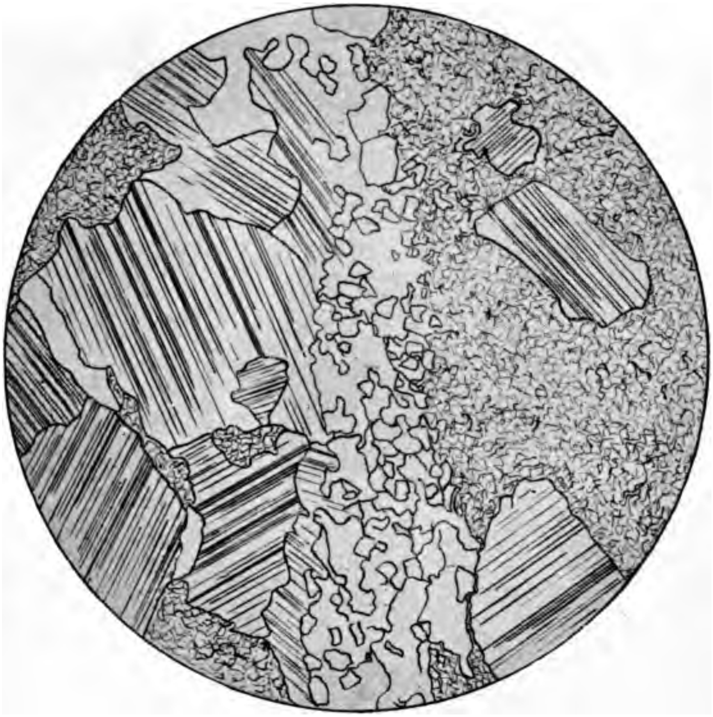
Specimen 5294, slide 862, × 120.

See pp. 117, 125.

Fig. *B*. Areas of secondary quartz extinguishing simultaneously within a corroded feldspar. The original identity of the feldspar is obliterated. The quartz is very transparent and free from inclusions.

Specimen 5400, slide 2477, × 150.

See pp. 51, 122, 120.



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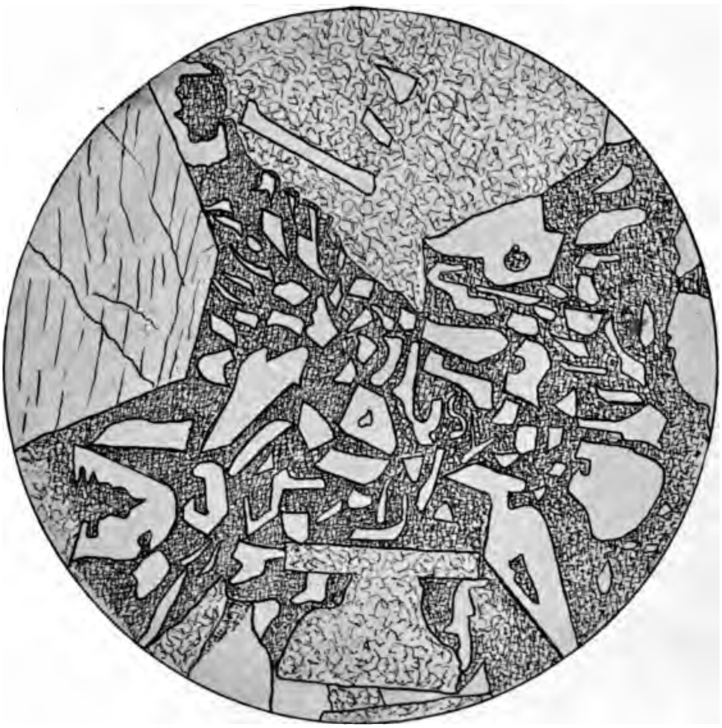


B

A, CONTACT OF FINELY GRANULAR DIKE AND HYPERSTHENE-FREE GABBRO.
B, AREAS OF QUARTZ EXTINGUISHING SIMULTANEOUSLY WITHIN A CORRODED FELDSPAR.

PLATE XXVII.

PLATE XXVII.

Fig. *A*. Peridotite, var. saxonite, showing enstatite and olivine, with the alteration products chiefly from olivine.

The light-brown portion (1) is a single individual of enstatite, in which the arrow marks the position of extinction. The enstatite individual is considerably shattered, and the fractures diverge as though they resulted from the hydration of the partially altered olivine. Such fracturing seen in certain forellensteins (troctolites) is attributed to that cause. The single olivine individual (2) shown in the central portion of the figure is at least one-half altered into serpentine and magnetite. The alteration has proceeded from the fractures, and the largest olivine areas occur where these fractures were least frequent. The serpentine (3) lies in strings and bands between the fresh olivine remnants.

Specimen 5216, slide 1785, × 180.

See p. 112.

Fig. *B*. Serpentine derived from the alteration of saxonite. A portion of the serpentine has been further replaced by quartz. Sec. 9, T. 112 N., R. 34 W.

Specimen 5216, slide 2221, × 180.

See p. 114.

(A)

(B)

PLATE XXVII.

Fig. A. [illegible]otite, var. saxonite, showing enstatite and olivine, with the alteration products [illegible] of olivine.

The right-hand portion (1) is a single individual of enstatite, in which the arrow [illegible] position of extinction. The enstatite individual is considered [illegible]red, and the fractures diverge as though they resulted from the [illegible] of the partially altered olivine. Such fracturing seen in cert[illegible] [illegible]ellensteins (troctolites) is attributed to that cause. The [illegible] individual (2) shown in the central portion of the figure is at [illegible] half altered into serpentine and magnetite. The alteration [illegible] from the fractures and the largest olivine areas occur where the [illegible]ures were least frequent. The serpentine (3) lies in strings and ba[illegible] between the fresh olivine remnants.

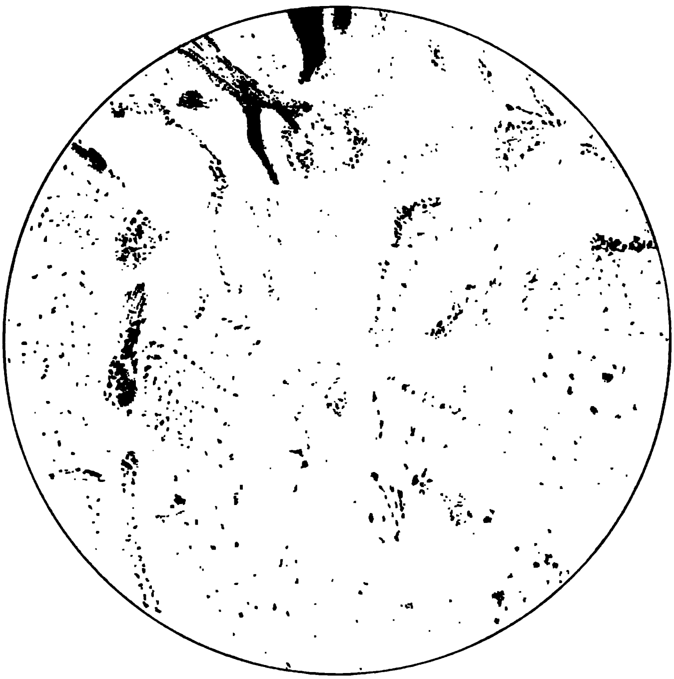
Specimen 5216, slide 178[illegible], × 180.

See p. 112.

Fig. B. Serpentine derived from the alteration of saxonite. A portion of the serpentine has been further replaced by quartz. Sec. 9, T. 112 N., R. 34 W. Specimen 5216, slide 2[illegible]1, × 180.

See p. 114.

(A)



(B)

JULIUS BIEN & CO. N.Y.

(A) ALTERED PERIDOTITE (B) SERPENTINE.

INDEX

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[Bulletin 157.]

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"The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classification of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization; and the money resulting from the sale of such publications shall be covered into the Treasury of the United States."

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